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CR 54301

DETERMINATION OF THE WELDABILITY AND ELEVATED TEMPERATURE STABILITY OF REFRACTORY METAL ALLOYS

Sixth Quarterly Report

by

G. G. Lessmann and D. R. Stoner

prepared for
National Aeronautics and Space Administration
Lewis Research Center
Space Power Systems Division
Under Contract NAS 3-2540

Astronuclear Laboratory
Westinghouse Electric Corporation

NOTICE

Astronuclear Laboratory

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Covering the Period

September 21, 1964 to December 20, 1964

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Contract NAS 3-2540

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FOREWORD

This report describes work accomplished under Contract NAS 3-2540 during the period September 21, 1964 to December 20, 1964. This program is being administered by R. T. Begley of the Astronuclear Laboratory, Westinghouse Electric Corporation. G. G. Lessmann and D. R. Stoner performed the experimental investigations.

Mr. P. E. Moorhead of the National Aeronautics and Space Administration is Technical Manager of this program.

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I. INTRODUCTION

This is the Sixth Quarterly Progress Report describing work accomplished under Contract NAS 3-2540. The objective of this program is to determine the weldability and long time elevated temperature stability of promising refractory metal alloys in order to determine those most suitable for use in advanced alkali-metal space electric power systems. A detailed discussion of the program and program objectives was presented in the First Quarterly Report. Alloys included in this investigation are listed in Table 1.

Process and test controls employed throughout this program emphasize the important influence of interstitial elements on the properties of refractory metal alloys. Stringent process and test procedures are required, including continuous monitoring of the TIG weld chamber atmosphere, electron beam welding at low pressures, aging in furnaces employing hydrocarbon free pumping systems providing pressures less than 10^{-8} torr, and chemical sampling following successive stages of the evaluation for verification of these process controls.

Equipment requirements and set-up, and procedures for welding and testing, have been described in previous progress reports. Any improvements in processes, changes in procedures, or additional processes and procedures are described in this report.

TABLE 1 - Alloys Included in the Weldability and Thermal Stability Evaluations

Alloy	Nominal Composition Weight Percent
AS-55	Cb-5W-1Zr-0.2Y-0.06C
B-66	Cb-5Mo-5V-1Zr
C-129Y	Cb-10W-10Hf+Y
Cb-752	Cb-10W-2.5Zr
D-43	Cb-10W-1Zr-0.1C
FS-85	Cb-27Ta-10W-1Zr
SCb-291	Cb-10W-10Ta
T-111	Ta-8W-2Hf
T-222	Ta-9.6W-2.4Hf-0.01C
Ta-10W	Ta-10W
W-25Re	W-25Re
W	Unalloyed
Sylvania "A"	W-0.5Hf-0.02C

Note: All alloys to be from arc-cast and/or electron beam melted material except Sylvania "A"

II. SUMMARY

The procurement phase of this program is essentially complete as shown in Table 2. This table reflects the considerable expenditure of time and effort required in obtaining these alloys. Procurement difficulties resulted primarily because the majority of these alloys, from the standpoint of production status, are semi-commercial or experimental.

The sheet butt weld parameter study has been completed for all available columbium and tantalum alloys and for W-25Re EB welds. Bend test results for alloys not previously reported are included in this report. These include TIG welds in AS-55, T-111, and T-222 and EB welds in these and C-129Y and B-66. A summary of current bend test results are given in Figure 1.

The bead-on-plate weld restraint patch test was run on T-111, T-222, and AS-55. These welds were defect free as determined by visual, radiographic, and penetrant inspections.

The first series of butt welds in 3/8 inch plate was bend tested. Included were transverse and longitudinal specimens of Ta-10W, SCb-291, Cb-752, C-129Y, D-43, B-66, and FS-85. Both transverse and longitudinal specimens of Ta-10W, FS-85, and SCb-291 displayed excellent ductility although the longitudinal specimens for FS-85 and SCb-291 failed at 125° and 160° bend angles respectively. The longitudinal specimen of C-129Y was bent through 132° without failure but the transverse specimen failed at 27°. Other alloys had poorer ductility.

Helium gas samples of the backfilled weld box were again taken and, using the technique of cryogenic concentration of impurities, were analyzed on a mass spectrometer. The oxygen concentration level in the as-backfilled chamber was found to be less than 0.25 ppm with a total active impurity concentration of less than 1.25 ppm. A specially procured ultra-high purity helium was used in this test. This grade is being used for all welding on this program.

TABLE 2 - Alloy Procurement and Delivery Schedule

Alloy	Approval	Quotation	Ordered	Shipping Date	Actual Delivery			Supplier
					Sheet	Plate	Wire	
AS-55	8/12/63	10/1/63	1/29/64	5/1/64	8/25/64	—[3]	—[3]	Gen. Electric (Cleveland)
B-66	8/12/63	8/19/63	8/29/63	10/18/63	3/3/64	3/3/64	11/8/63	Westinghouse
C-129Y	8/12/63	9/20/63	10/2/63	11/30/63	12/24/63	3/13/64	3/13/64	Wah Chang
Cb-752	8/12/63	9/19/63	10/21/63	11/30/63	12/31/63	12/18/63	12/31/63	Haynes
D-43	8/12/63	8/17/63	9/3/63	11/8/63	11/15/63	10/18/63	2/12/64	Du Pont
FS-85	8/12/63	8/12/63	8/22/63	1/30/64	3/6/64	1/6/64	3/7/64	Fansteel[1]
SCb-291	8/12/63	9/17/63	10/2/63	1/30/64	1/9/64	1/8/64	12/6/63	Fansteel
T-111	8/12/63	8/16/63 6/25/64[2] 6/25/64	9/27/63 8/5/64 —[5]	10/28/63 9/28/64 —[5]	—[4] 11/17/64 —[4]	12/31/63 —[4] —[4]	—[4] —[4] 8/14/64	NRC Wah Chang Westinghouse
T-222	2/28/64	6/29/64[2]	7/20/64	9/28/64	12/16/64	12/16/64		Wah Chang
Ta-10W	8/12/63	8/12/63	8/22/63	9/30/63	10/21/63	10/3/63	10/17/63	Fansteel
W-25Re	8/12/63	11/26/63	2/1/64	4/1/64	5/29/64	—[3]	—[3]	Wah Chang
W	2/28/64	2/19/64	4/16/64	6/15/64	7/30/64	—[3]	—[3]	Universal Cyclops
Sylvania "A"	6/24/64	5/15/64	5/15/64	9/30/64	3/1/65	—[3]	—[3]	Sylvania

1. Sheet material produced by Fansteel under Contract NOw-63-0231-c and furnished to this program as transferred government owned material.
2. Second procurement action for this material
3. Not included in program.
4. T-111 order split between three suppliers.
5. Converted at Westinghouse Astronuclear Laboratory.

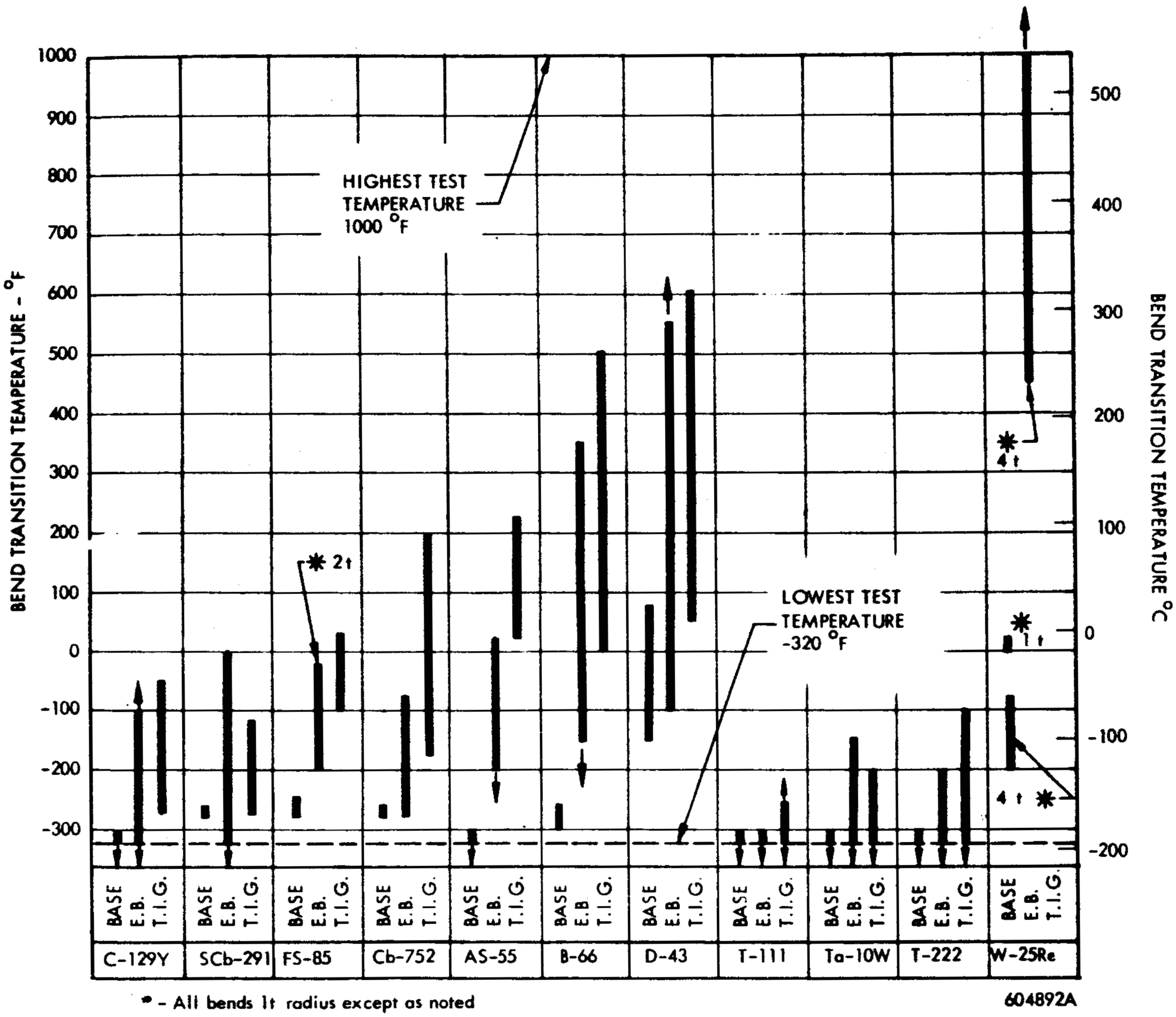


FIGURE 1 - Summary of Current Bend Test Results for Butt Welds in 0.035 Inch Sheet.

III. TECHNICAL PROGRAM

A. ALLOY PROCUREMENT

The procurement status of the alloys included in this program is shown in Table 2. During this period the T-222 sheet and plate and T-111 sheet were delivered. A summary of chemical compositions for the as-received alloys is given in Table 3, while hardness and grain size values are given in Table 4. Base metal microstructures for T-111 and T-222 are shown in Figures 2 and 3, while the respective base metal bend test results are given in Figures 5 and 6. The AS-55 base metal oxygen level was rechecked and found to be high (630 to 950 ppm) in all sheets. Consequently, this particular material is not considered a representative commercial grade and no testing of this alloy will be conducted beyond that included in this report.

B. WELDING EVALUATIONS

1. TIG Sheet Welding

Sheet welding has been completed for ten alloys for the parameter optimization phase. Bend test results for the three alloys completed during this period, including T-111, T-222, and AS-55, are presented in this report. Results on other alloys were reported earlier. TIG welding procedures and equipment were described in detail previously. The "key" for the bend test data presentation is given again for convenience in Figure 4.

During the previous reporting period, a change in helium supply was made. Ultra-high purity helium purchased from Air Products and Chemicals, Inc., is now being used for backfilling the TIG weld chamber. This has resulted in a considerable improvement in backfilled chamber purity. The welding atmosphere oxygen level has now been reduced to less than 0.25 ppm oxygen and 1.25 ppm total active impurities compared with 1.2 to 2.3 ppm and 5.3 to 11.3 respectively for a standard grade helium. The following analyses of backfilled chamber helium have been obtained.

Analysis in ppm(1)

Sample No.	Helium	O_2	N	CO_2	H_2	$C_2H_2Cl_4$ (2)	A	Ne	Total	Total Active (3)
1	Standard	1.2	3.4	0.1	0.6	6.7	0.9	7.3	20.2	5.3
5	Standard	2.3	8.4	0.4	0.2	0.4	1.3	9.7	22.7	11.3
8	High Purity	0.18	0.7	0.0	0.26	0.0	0.13	6.26	7.53	1.14
9	High Purity	0.17	0.68	0.0	0.21	2.52	0.14	5.0	8.72	1.06

(1) Moisture, all: not detectable
(2) Chlorinated hydrocarbons
(3) Does not include chlorinated hydrocarbons since these have been noted only when using one particular sample bottle and are therefore felt to result from residual sample bottle contamination.

The following observations were made in evaluating the TIG sheet butt weld bend test results:

<u>T-111 TIG Welds (See pages 36 - 38 for test data)</u> - This alloy has excellent weldability which is apparently unaffected over a broad range of welding conditions. Welds were defect free as determined by visual, dye penetrant and radiographic inspection. For all but two welds, this alloy exhibited no ductile to brittle bend transition temperature down to the lowest test point, -320°F. A small weld crack occurred in the transverse test of weld No. 2 at -320°F. Weld tears occurred in all three longitudinal specimens of weld No. 11. However, the target 90° to 105° bends were obtained on all specimens. These results are in essential agreement with the favorable results reported previously in other programs.[1,2] This alloy appears to possess excellent fabricability combined with high strength. Strengthening of this alloy is apparently accomplished primarily by solid solution.

<u>T-222 TIG Welds (See pages 42-44 for test data)</u> - Nine of twelve welds in this alloy were entirely ductile down to the lowest bend test temperature, -320°F. The highest transition temperature was noted for weld No. 11, -100°F. No visual or dye penetrant weld defects were observed. However, five welds indicated porosity in radiography. All porosity occurred at welding speeds of less than 30 inches per minute. Since this problem was entirely unexpected, it is now receiving close attention. Radiography is being complemented by metallography and spectographic analyses in an effort to determine the cause of and extent of the weld porosity problem. Except for the weld porosity, T-222 like T-111 possesses a combination of fabricability and high strength. The T-222 alloy strength exceeds T-111 because of the addition of 100 ppm carbon and slightly higher hafnium and tungsten levels. Despite the carbon addition, this alloy also appears to realize its strength from solid solution.

<u>AS-55 TIG Welds (See pages 23-25 for test data)</u> - Bend transition temperatures for this alloy were fairly consistent varying over a 200°F range from +25°F to 225°F. These values appear to agree with reported test data.[3] Many of the specimen failures occurred near the 90 to 105° target bends as small weld cracks and generally not as total specimen fractures. Unfortunately the carbon and oxygen contents of this material are out of spec which results in considerable difficulty in evaluating this alloy. The carbon appears to be low (300 to 440 ppm) while the oxygen is excessively high (630-930 ppm). Considering the oxygen level, this alloy is remarkable ductile demonstrating the beneficial effect of yttrium. The yttrium resulted in considerable slagging at the weld producing a discontinuous black film over approximately 30 per cent of the weld surface, Figure 11. Because the oxygen level is so abnormally high, no further work will be conducted on this alloy.

2. EB Sheet Welding

A complete set of welds for the parameter optimization phase was produced for the tantalum base alloys, T-111 and T-222 and columbium base alloys C-129Y, B-66, and AS-55. The welds were bend tested and the results are discussed below.

The bend transition temperatures indicated are, as described in the previous quarterly report, and shown in Figure 4, those at which a 90° to 105° bend was obtained without cracking on the tension side of the specimen.

T-111 EB Welds (See pages 33-35 for Test Data) - As in the TIG weld evaluation, this alloy demonstrated excellent weldability with all twelve of the weld parameters producing ductile bends at liquid nitrogen temperature (-320°F). All but the two high speed (100 ipm) welding passes produced welds of acceptable external appearance. Since the transition from ductile-to-brittle bend behavior was below the lowest test temperature for all the parameters evaluated, welds were judged by weld physical appearance. The slow speed weld at 15 ipm, 1/2 inch wide clamp spacing and 0.050 inch longitudinal deflection, produced the flatest weld with the highest expected joint efficiency.

T-222 EB Welds (See pages 39-41 for Test Data) - The weld bend transition temperature range for the parameter evaluation of T-222 is tentatively from -200°F to less than liquid nitrogen temperature, -320°F. All weld parameters except one were ductile to -320°F and this weld was found to be misaligned along the weld joint resulting in less than 100% weld penetration. This parameter will be rewelded and retested.

On the basis of weld radiography and physical appearance, the weld at 15 ipm, 0.050 inch longitudinal deflection, and wide clamp spacing of 1/2 inch produced the best weld. The other weld parameters demonstrated more undercutting and buildup on the top and bottom weld surfaces. This alloy is obviously adaptable to a wide range of welding conditions.

AS-55 EB Welds (See pages 20-22 for Test Data) - AS-55 was readily electron beam welded with approximately a 200°F increase in bend transition temperature following welding. The overall range of transition temperatures was from -200°F to 25°F. Two of the twelve weld parameters produced structurally defective welds, but these did not affect the spread in bend test results. Longitudinal bend test fractures initiated in the weld and heat affected zone were generally arrested in the base metal. Weld clamp spacing did not affect the extent of fracture propagation in the longitudinal specimens. Transverse bend test specimens fractured with equal frequency along the weld centerline and in the heat affected zone indicating that weld and heat affected zone embrittlement are about equally important. No slagging was observed on the surface of the EB welds as was seen on the TIG welds.

The absence of slagging could perhaps be attributed to a breakdown of the stable yttrium oxide, Y_2O_3, by the high power density electron beam and consequent volatilization as a sub-oxide such as YO.

Slower welding speeds produced welds of lower ductile-brittle transition temperatures. The three best welds were made at 15 to 25 ipm welding speed with 0.050 inch longitudinal beam deflection.

B-66 EB Welds (See pages 27-29 for Test Data) - The large weld bend transition temperature range obtained, (from -150°F to 350°F), was apparently caused by the large number of structurally defective welds produced using the typical range of weld parameters. Seven of the twelve welds displayed a severe rippled pattern effectively producing stress raisers in the weld. Other alloys welded with the same parameters, but adjusted for uniform weld size by power input did not suffer the same problems. Although a susceptability to rippling cannot be predicted, frequently alloys containing a major alloying constituent of high vapor pressure and/or which significantly increase the liquidus-solidus separation are troublesome. Vanadium may contribute to both these factors in B-66. Excluding the structurally defective welds, the transition temperature range is reduced to -100°F to 150°F.

The transition from brittle to ductile behavior with temperature was abrupt, but the majority of the weld and heat affected zone initiated longitudinal bend fractures were arrested in the base metal. Transverse bend tests usually produced fractures along the weld centerline.

Good welds with low bend transition temperatures were obtained at moderate speeds of from 25 to 50 ipm with 0.050 inch longitudinal deflection. The best combination of physical appearance and low bend transition temperature, -100°F, was obtained with weld number 7 using 25 ipm, with 0.050 inch longitudinal beam deflection and the narrow 3/16 inch clamp spacing.

C-129Y EB Welds (See pages 30-32 for Test Data) - The weld bend transition range for C-129Y was from -100°F to less than -320°F. The transition from ductile-to-brittle behavior with temperature occurred abruptly with the longitudinal specimens showing little tendency for the base metal to arrest cracks initiated in the weld and heat affected zone. Transverse fractures propagated equally through the weld centerline and heat affected zone to within 3/32 to 1/4 inch of the weld. The ductile transverse bend at -320°F for weld number 7 was obtained because most of the bend angle straining occurred in the weaker heat affected zone. Longitudinal bends which equally strain the weld metal, heat affected zone, and base metal, were not ductile below -200°F.

No definite trend was observed on the effect of weld speed and clamp spacing on weld bend ductility. The best combination of weld bend ductility and physical appearance was obtained at 50 ipm with the wide 1/2 inch clamp spacing and 0.050 inch longitudinal beam deflection.

3. Plate Weld Bend Tests

The first series of 0.375 inch plate butt welds were bend tested during this period. The double "U" design for this joint and welding schedules were presented in the Third Quarterly Report on this program. All plate bend testing is being done at room temperature. The bend test fixture is shown in Figure 24. Each specimen is bend tested in three stages using successively sharper punch radii. The three punches have radii of 16t, 8t, and 3t. These are used to produce successive respective bend angles of approximately 25°, 40°, and 140°.

The results of these tests, including bend data on each successive bend, are given in Table 13. Among the columbium alloys, FS-85 and SCb-291 were most ductile and B-66 was least ductile. Both the transverse and longitudinal specimen of Ta-10W were bent to maximum deflection (141°) over the 3t radius without failure. The bend tested specimens are shown in Figures 25 to 28.

4. Weld Restraint Tests

The bead-on-plate weld restraint patch tests were welded for T-111 and T-222 (Figure 29) and AS-55 (Figure 30). These specimens were inspected visually, radiographically and with dye-penetrant and were found to be defect free. All three alloys distorted considerably but only to the approximate extent which has been observed for the other program alloys.

IV. FUTURE WORK

It is anticipated that preparation of welds for the weld thermal stability study will be largely completed during this period. Post weld annealing studies will also be completed for the tantalum and columbium based alloys.

A study to determine the effect of variations in base metal interstitial contamination levels on the weldability of T-111, T-222, and FS-85 has been initiated. Preliminary results of this program will become available during the next period.

V. REFERENCES

1. G. E. Gazza and T. S. DeSisto, "Evaluation of Refractory Metal Sheet Alloys," U.S. Army Materials Research Agency, Technical Report AMRA-TR-64-16, July, 1964.

2. R. L. Ammon, R. T. Begley, "Pilot Production and Evaluation of Tantalum Alloy Sheet," Summary Phase Report, Westinghouse Astronuclear Laboratory, WANL-PR-M-004, August 15, 1963, Bureau of Naval Weapons, Contract NOw-62-0656-d.

3. R. G. Carlson, D. N. Miketta, R. G. Frank, and J. W. Semmel, Jr., "Evaluation of a High Strength Columbium Alloy (AS-55) for Alkali Metal Containment," Interim Report, NASA Contract NAS 3-2140, General Electric, GE 62FPD365, July, 1962.

TABLE 3 - Chemistry of As-Received Material

Alloy	Form	Heat	Certified Analysis (Avg.)												Check Chemistry		
			w/o									ppm			ppm		
			Zr	Hf	Mo	V	Y	Re	W	Ta	Cb	C	O	N	C	O_2	N_2
AS-55	Sheet	430-7	1.07				0.02-0.3		4.74		Bal.	306	190-600	155	440	530-930	200
B-66	Plate	DX-609	1.00		5.17	4.89					Bal.	95	110	63	37	120	70
	Sheet	DX-609	1.00		5.17	4.89					Bal.	95	110	63	44	150	30
	Wire	DX-569	1.10		5.23	5.61					Bal.	17	70	64	130	140	90
		DX-603	0.92		4.55	4.85					Bal.	40	82	75	130	190	50
C-129Y	Plate	6.6-57033		10.25					10.8		Bal.	65	160	15	58	200	30
		610-57204		10.10					10.85		Bal.	80	50	58			
	Sheet	46-70617		9.5			0.105		9.8	0.135	Bal.	85	105	50	36	102	60
	Wire	6.6-57033		10.25					10.8		Bal.	65	160	15	52	120	50
Cb-752	Plate	52165	2.70						9.8		Bal.	50	76	10	16	84	70
	Sheet	52208	2.90						9.9		Bal.	40	143	102	21	180	80
	Wire	52183	2.90						9.6		Bal.	30	60	120	51	120	90
D-43	Plate	43-398-13	0.97						10.3		Bal.	835	63	32	930	64	20
	Sheet	43-398-13	1.00						9.9		Bal.	1046	200	32	1100	180	10
	Wire	43-372-1	0.88						9.7		Bal.	810	52	33		85	60
FS-85	Plate	85D-740	0.94						10.6	28.1	Bal.	20	90	60			
	Sheet	85D-739	0.95						10.43	27.61	Bal.	40	40	52	12	98	50
	Wire	85D-695	0.97						10.2	28.0	Bal.	20	40	30	34	73	40
SCb-291	Plate	2255							10.0	9.83	Bal.	20	110	40	22	101	20
	Sheet	1991							9.9	9.6	Bal.	12	65	76	17	110	50
	Wire	1825							10.1	9.2	Bal.	10	67	70	12	130	50
Ta-10W	Plate	60B-758							9.90	Bal.		50	40	20	5	10	10
	Sheet	60B-758							9.90	Bal.		50	40	20	12	66	100
	Wire	60B-609															
T-111	Plate	2691		1.7					7.05	Bal.		18.5	10	26	27	34	10
	Sheet	6-65042-Ta		2.0					8.8	Bal.		80	50	35	48	15	19
	Wire	DX-571		2.01					8.12	Bal.		10	20	10	17	23	20
T-222	Plate	5.510-65041		2.55					9.2	Bal.		115	50	20			
	Sheet	5.510-65041		2.55					9.2	Bal.		115	50	20	100	29	10
	Wire																
[illegible]-Re	Sheet	3.5-75002							25.6	Bal.		40	50	35	8	8	10
[illegible]	Sheet	KC-1350								Bal.					6	10	10
		KC-1353								Bal.					9	15	10

TABLE 4 - Hardness and Grain Size of As-Received Material

Alloy	Form	Hardness DPH	ASTM Grain Size
AS-55	Sheet	148	9
B-66	Plate	225	6
	Sheet	219	10
C-129Y	Plate	218	
	Sheet	185	10
Cb-752	Plate	204	8
	Sheet	205	8-9
D-43	Plate	202	
	Sheet	220	5
FS-85	Plate	205	7
	Sheet	190	8
SCb-291	Plate	160	6
	Sheet	175	6
Ta-10W	Plate	197	8
	Sheet	221	6-7
T-111	Plate	223	6-7
	Sheet	221	9
T-222	Plate	276	7-8
	Sheet	273	7-8
W-25Re	Sheet	526	*
		492	
W	Sheet	517	*

* Stress Relieved, Not Recrystallized

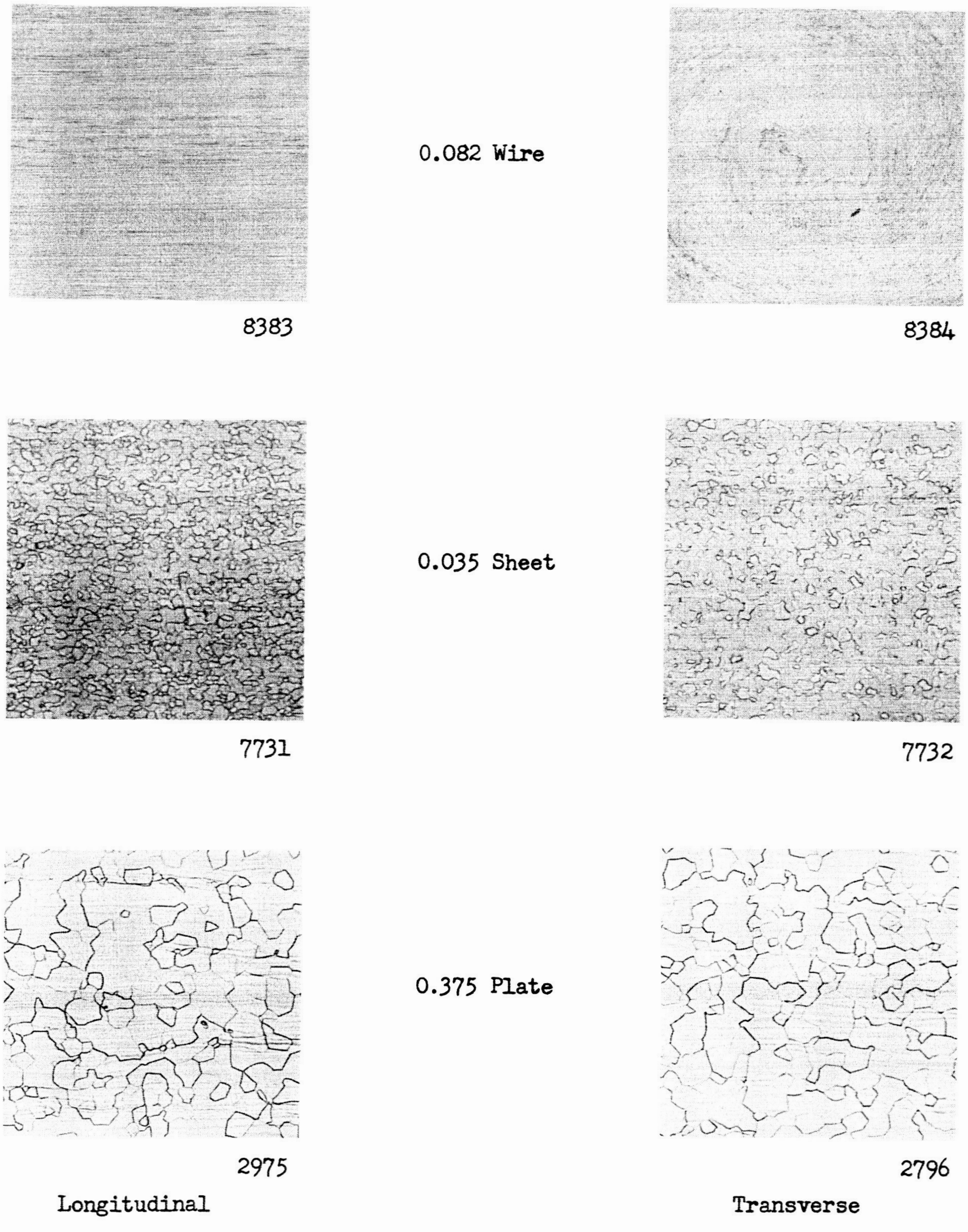
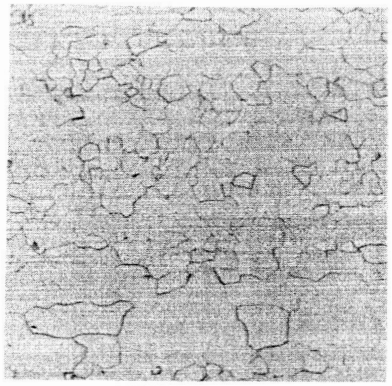
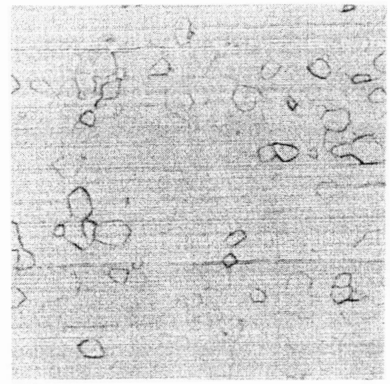


FIGURE 2 - Microstructures of As-Received T-111, 100X
(HNO_3-$NH_4F \cdot HF$ Etch)



0.035 Sheet



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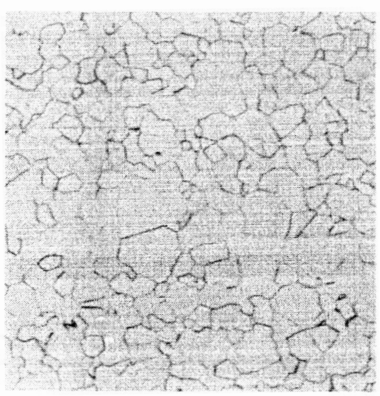
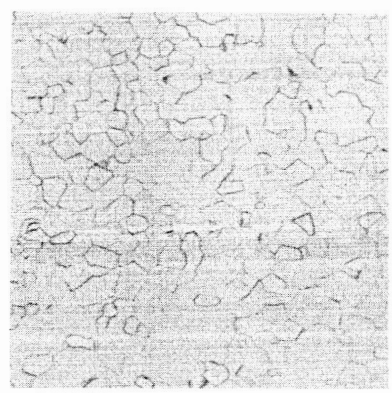
8386



0.375 Plate



8387

Longitudinal

8388

Transverse

FIGURE 3 - Microstructures of As-Received T-222, 100X
(HNO_3-$NH_4F \cdot HF$ Etch)

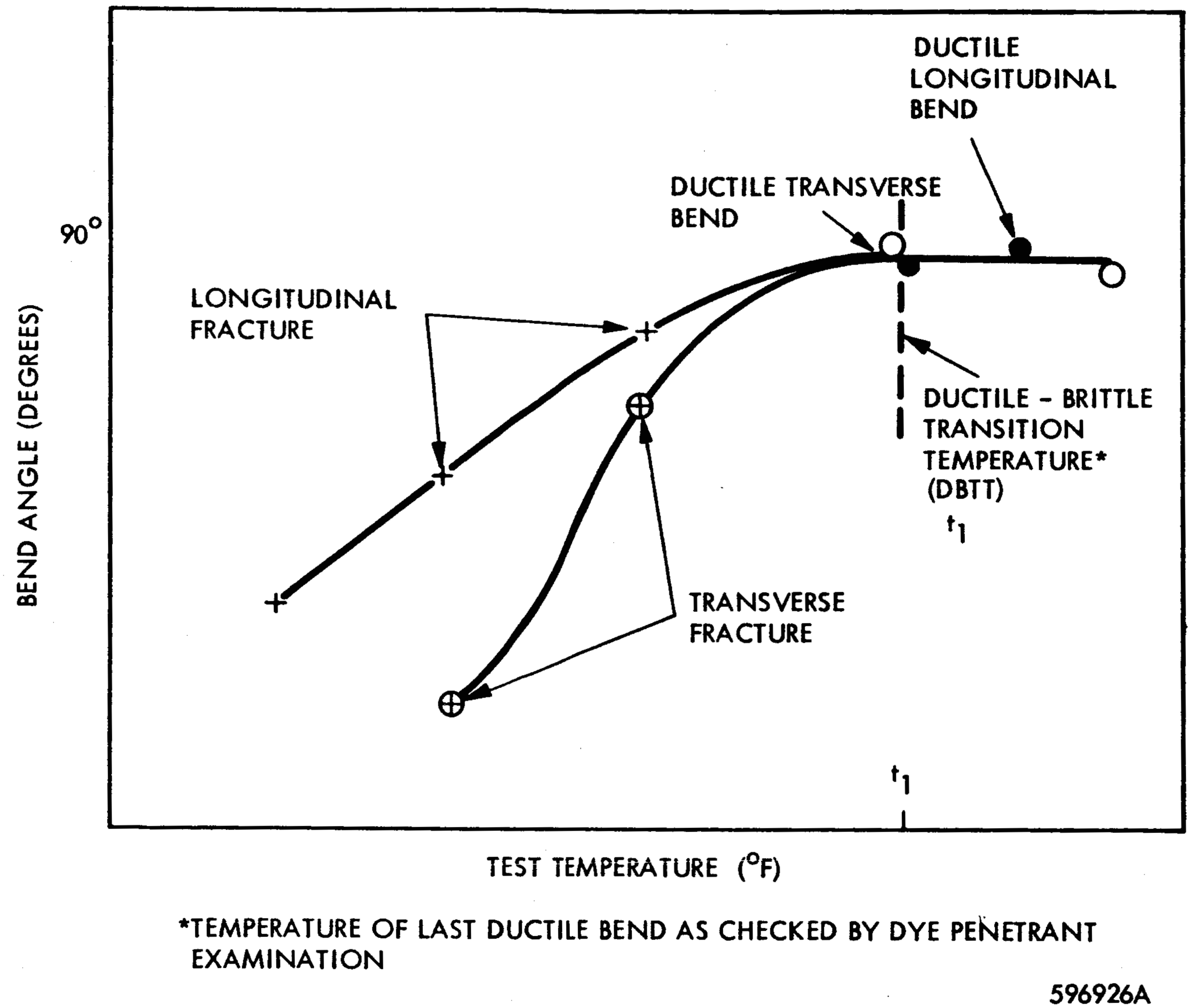


FIGURE 4 - Key for Presentation of Bend Test Data

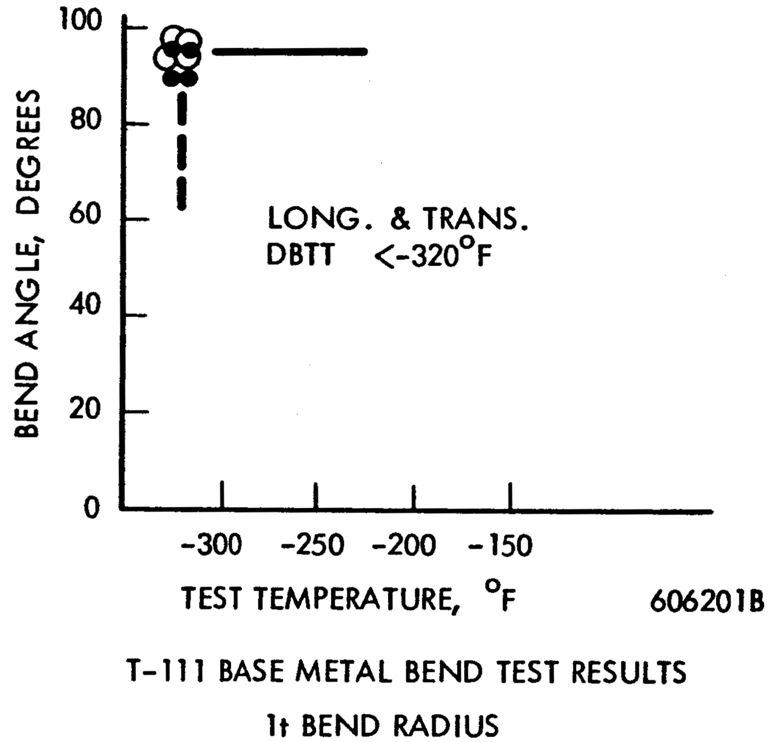


FIGURE 5 - T-111 Base Metal Bend Test Results

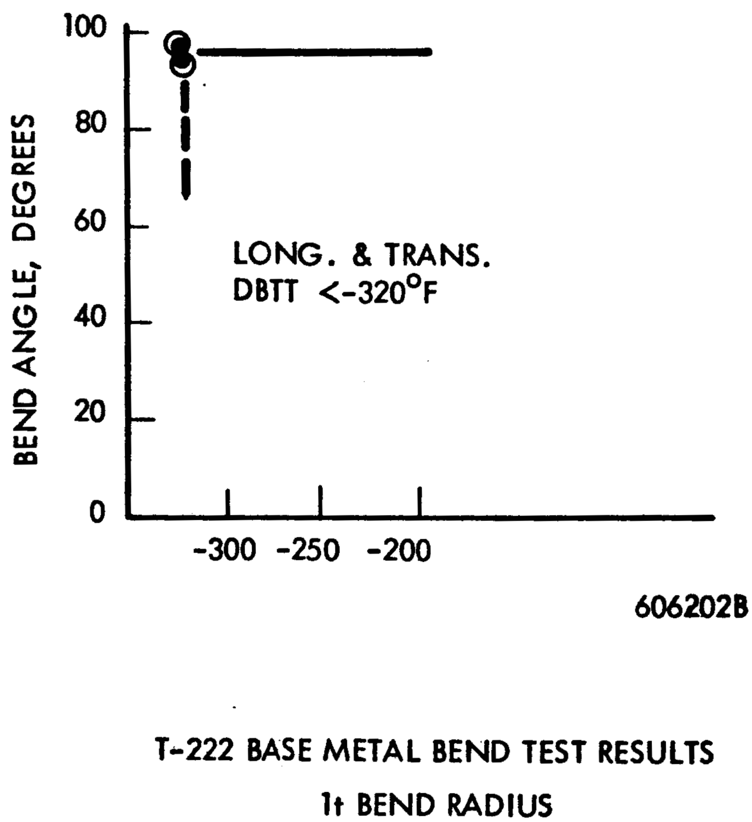


FIGURE 6 – T-222 Base Metal Bend Test Results

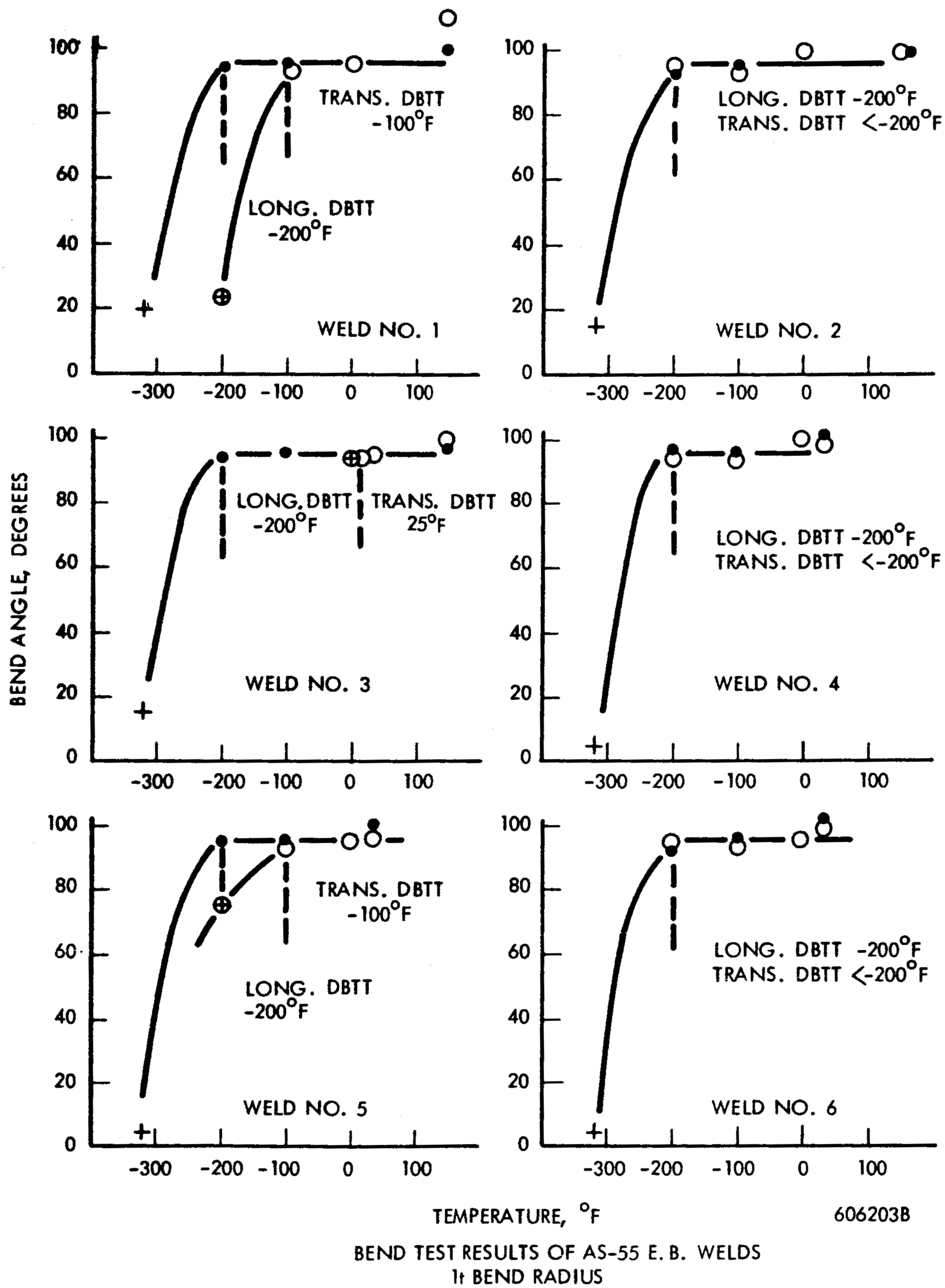
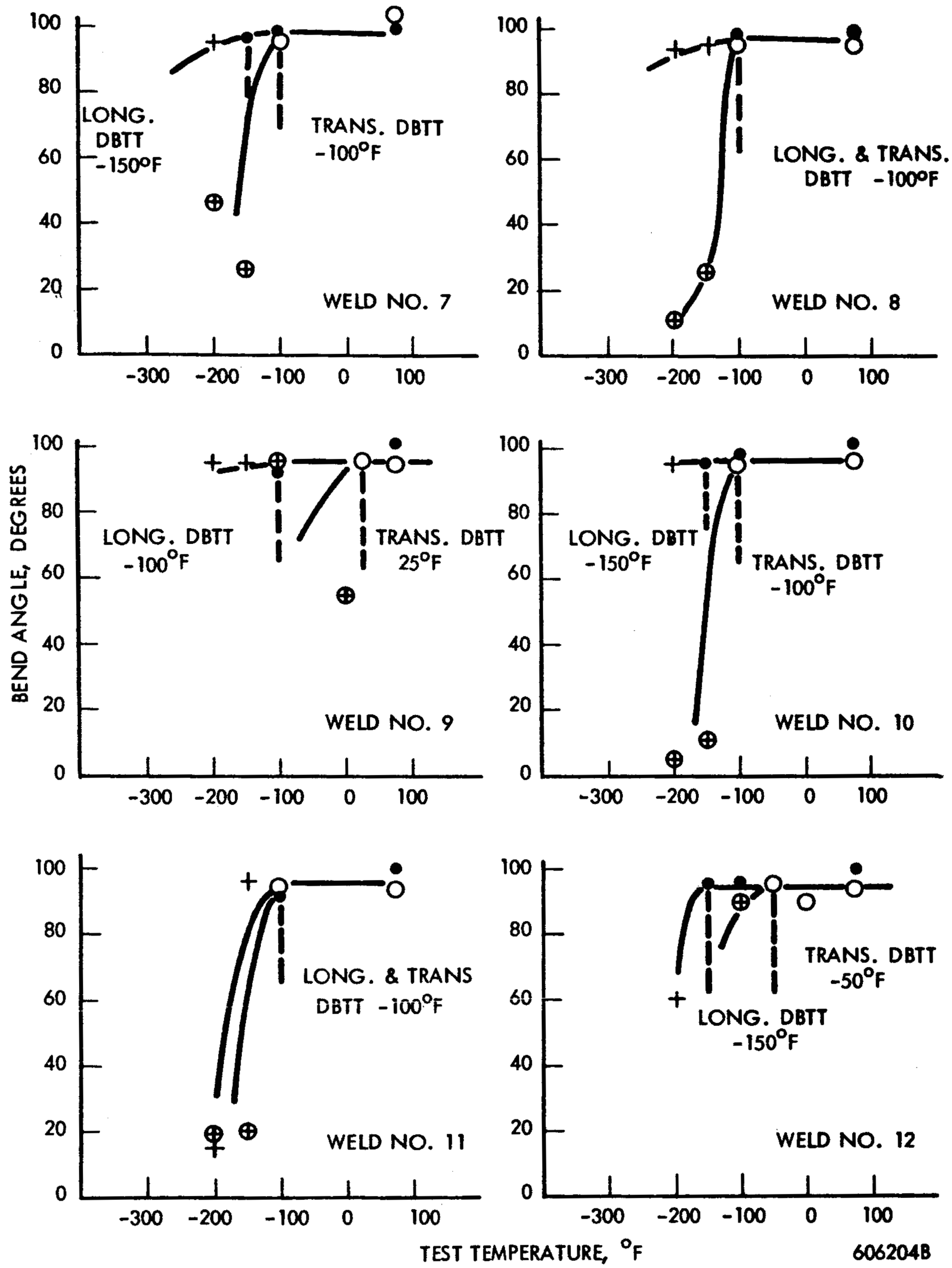


FIGURE 7 - AS-55 EB Weld Bend Test Results



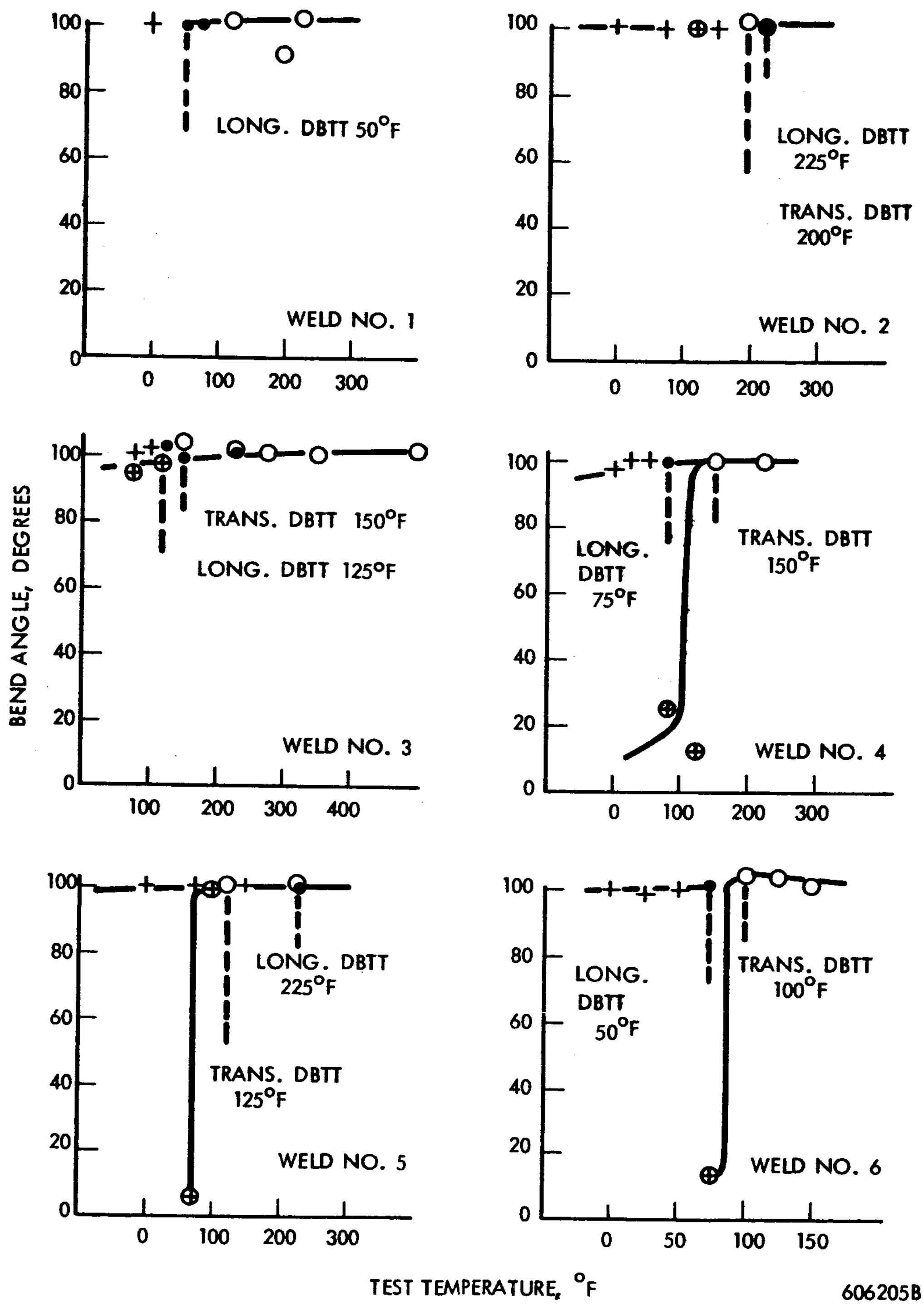
BEND TEST RESULTS OF AS-55 E. B. WELDS
1t BEND RADIUS

FIGURE 8 - AS-55 EB Weld Bend Test Results

TABLE 5 - AS-55 Sheet. EB Butt Weld Record

Weld No.	Speed (ipm)	Deflection[1] (Inches)	Current (ma)	Chill Spacing (Inches)	Power (watts)	Watt-Sec. per inch	Weld Bead Width (Inches) Top	Weld Bead Width (Inches) Bottom	Vacuum torr
1	15	Zero	2.8	.094	420	1680	.027	.023	3.6×10^{-6}
2	15	L - .050	3.4	.094	510	2040	.044	.023	3.6×10^{-6}
3	15	T - .050	3.4	.094	510	2040	.062	.057	3.6×10^{-6}
4	25	L - .050	3.6	.094	540	1300	.045	.027	3.6×10^{-6}
5	15	L - .050	3.1	.250	465	1860	.044	.031	3.6×10^{-6}
6	25	L - .050	3.3	.250	495	1190	.040	.027	3.6×10^{-6}
7	50	L - .050	3.7	.250	555	667	.033	.020	3.6×10^{-6}
8	100	L - .050	4.9	.250	735	440	.033	.020	3.6×10^{-6}
9	50	Zero	3.8	.094	570	684	.025	.018	3.0×10^{-6}
10	50	L - .025	4.1	.094	615	740	.034	.021	3.0×10^{-6}
11	50	L - .050	4.1	.094	615	740	.036	.022	3.0×10^{-6}
12	100	L - .050	5.4	.094	810	485	.030	.020	3.0×10^{-6}

All welds made at 150 KV.
1. L. is longitudinal
   T. is transverse



AS-55 TIG WELD BEND TEST RESULTS

FIGURE 9 - AS-55 TIG Weld Bend Test Results

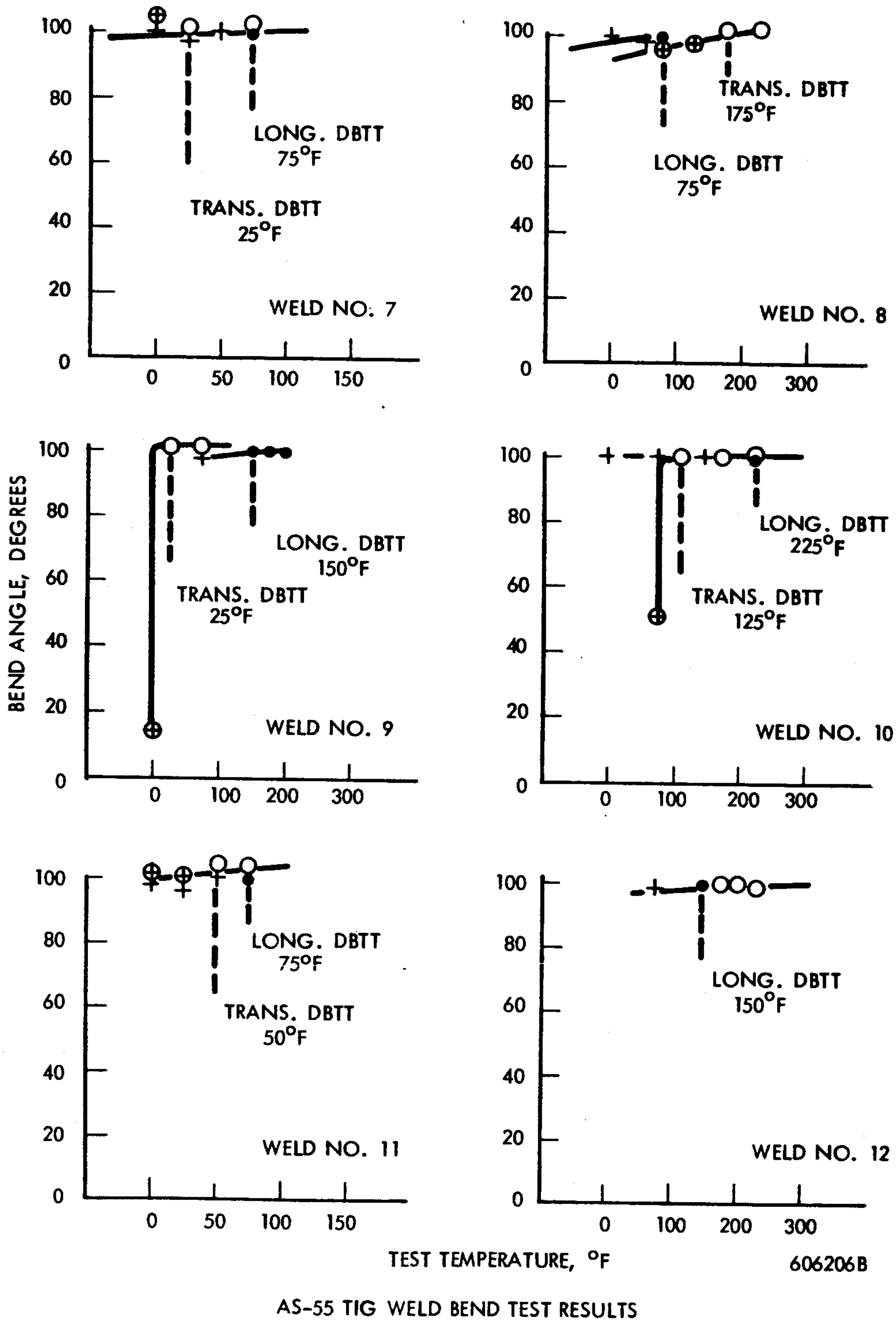


FIGURE 10 - AS-55 TIG Weld Bend Test Results

TABLE 6 - AS-55 Sheet. TIG Butt Weld Record

Weld No.	Clamp Spacing (Inch)	Speed (ipm)	Current Amperes	Weld Width Top/Bottom (Inch)	Q Joules/Inch	Atmosphere Monitor Readings			Comments	
						O_2(1) ppm	O_2(2) ppm	H_2O(3) ppm	Visual Inspection	Dye Check
1	1/4	7.5	57	0.099/0.075	6380	0.7	1.0	0.4	Negative	Negative
2	1/4	7.5	80	0.150/0.135	8950	---	1.1	0.6	Negative	Negative
3	1/4	1.5	95	0.165/0.150	5700	0.5	2.0	0.9	Negative	Negative
4	3/8	15.0	81	0.180/0.150	5190	1.4	2.0	0.7	Negative	Negative
5	1/4	15.0	69	0.108/0.069	3860	0.5	1.5	0.8	Negative	Negative
6	3/8	15.0	62	0.132/0.069	3720	1.9	2.0	0.9	Negative	Negative
7	1/4	30.0	90	0.132/0.045	2700	0.8	2.2	1.0	Negative	Negative
8	3/8	30.0	85	0.120/0.048	2720	3.0	1.5	1.5	Negative	Negative
9	1/4	30.0	149	0.192/0.174	5070	---	2.3	1.1	Negative	Negative
10	3/8	30.0	120	0.165/0.138	4080	3.0	1.7	1.8	Negative	Negative
11	3/8	60.0	151	0.159/0.090	2565	1.3	2.5	1.2	Negative	Negative
12									Burn	Through

(1) Westinghouse Oxygen Gage
(2) Lockwood & McLorie Oxygen Gage
(3) CEC Moisture Monitor

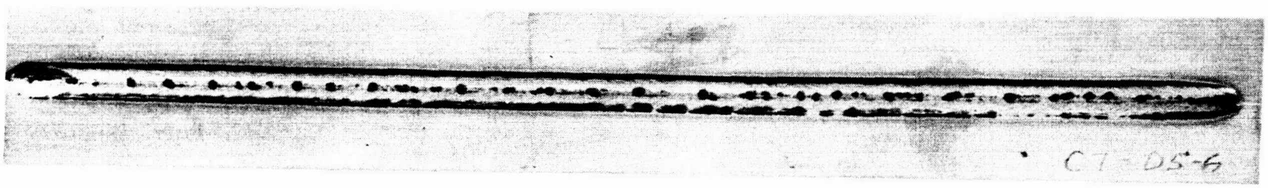
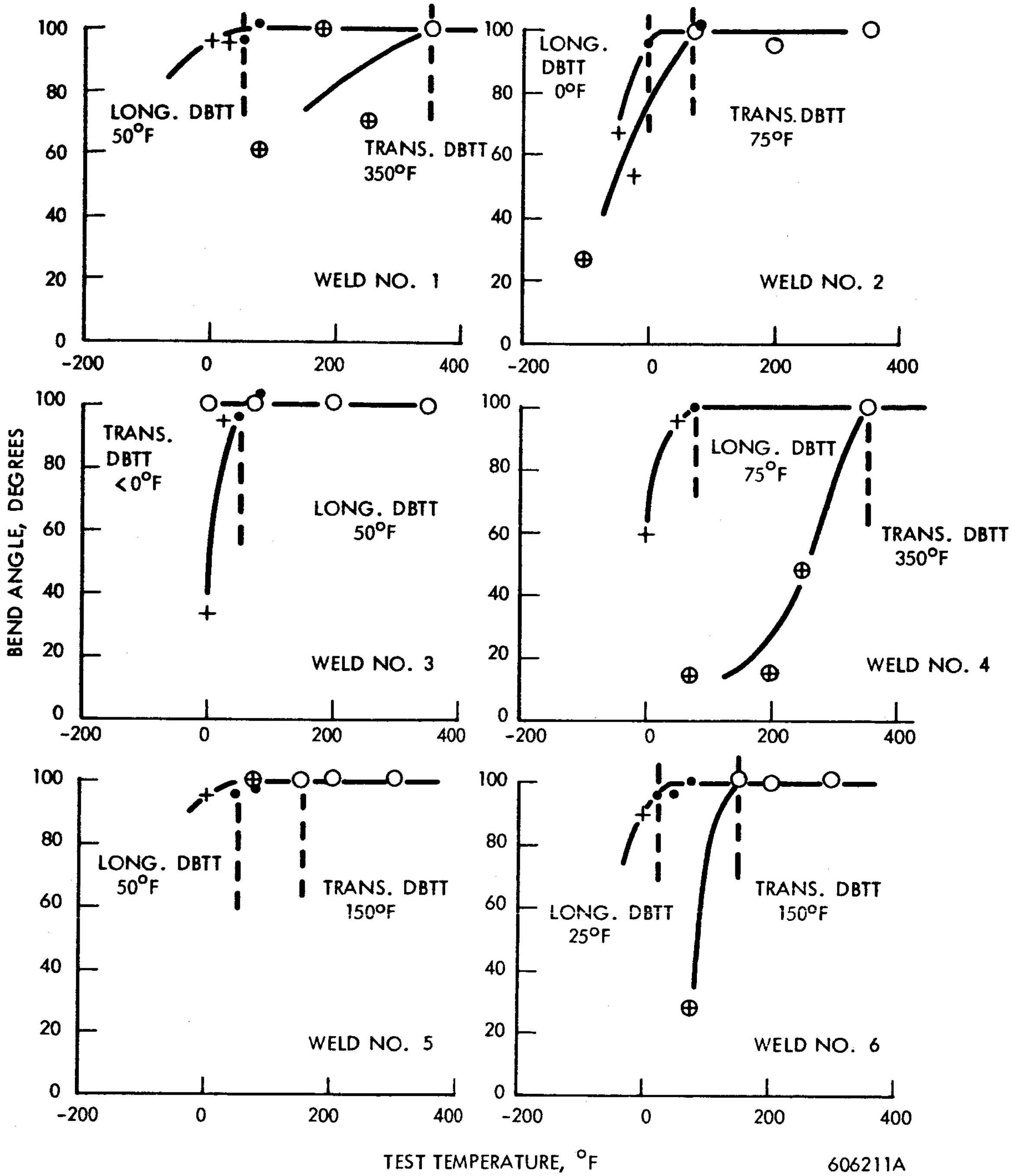


FIGURE 11 - AS-55 Sheet Butt Weld



BEND TEST RESULTS OF B-66 E. B. WELDS
1t BEND RADIUS

FIGURE 12 - B-66 EB Weld Bend Test Results

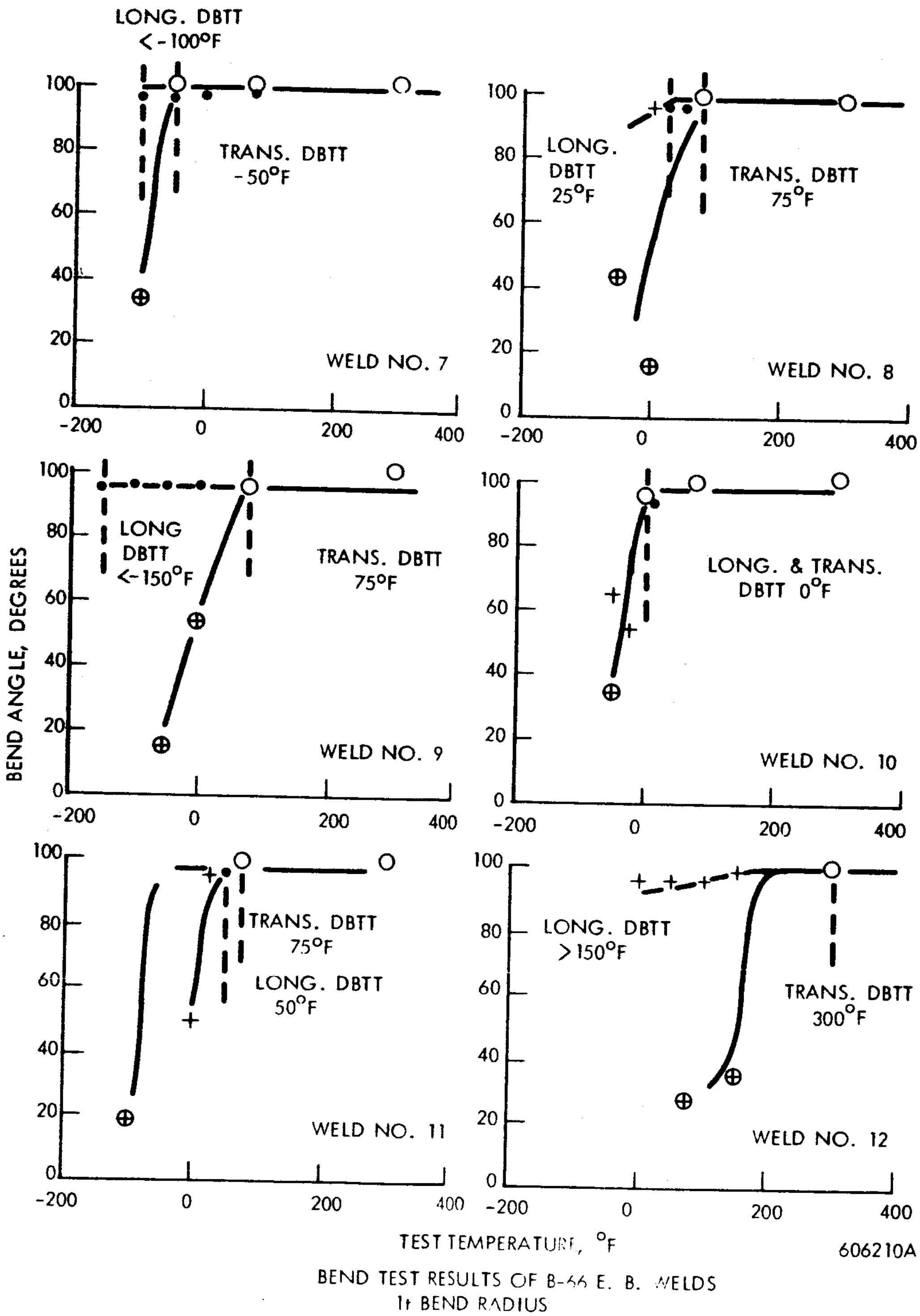


FIGURE 13 - B-66 EB Weld Bend Test Results

TABLE 7 - B-66 Sheet. EB Butt Weld Record

Weld No.	Speed (ipm)	Deflection[1] (Inches)	Current (ma)	Chill Spacing (Inches)	Power (watts)	Watt-Sec. per inch	Weld Bead Width (Inches)		Vacuum torr	Ave. Weld Bead Width
							Top	Bottom		
1	15	Zero	2.4	.094	360	1440	.027	.016	1.7×10^{-6}	.022
2	15	L - .050	2.8	.250	420	1680	.040	.027	1.7×10^{-6}	.034
3	50	L - .050	3.5	.250	525	630	.033	.022	3.8×10^{-6}	.028
4	100	L - .050	4.6	.250	690	413	.027	.020	3.8×10^{-6}	.024
5	15	L - .050	3.0	.094	450	1800	.034	.020	3.8×10^{-6}	.027
6	15	T - .050	3.0	.094	450	1800	.056	.054	3.8×10^{-6}	.055
7	25	L - .050	3.2	.094	480	1150	.036	.024	3.8×10^{-6}	.030
8	50	Zero	3.4	.094	510	612	.022	.016	4.0×10^{-6}	.019
9	50	L - .025	3.4	.094	510	612	.030	.018	4.0×10^{-6}	.024
10	50	L - .050	3.8	.094	570	684	.031	.022	4.0×10^{-6}	.026
11	50	L - .100	4.6	.094	690	829	.032	.027	1.9×10^{-6}	.030
12	100	L - .050	5.0	.094	750	450	.033	.032	4.7×10^{-6}	.032

All welds made at 150 KV.
1. L. is longitudinal
   T. is transverse

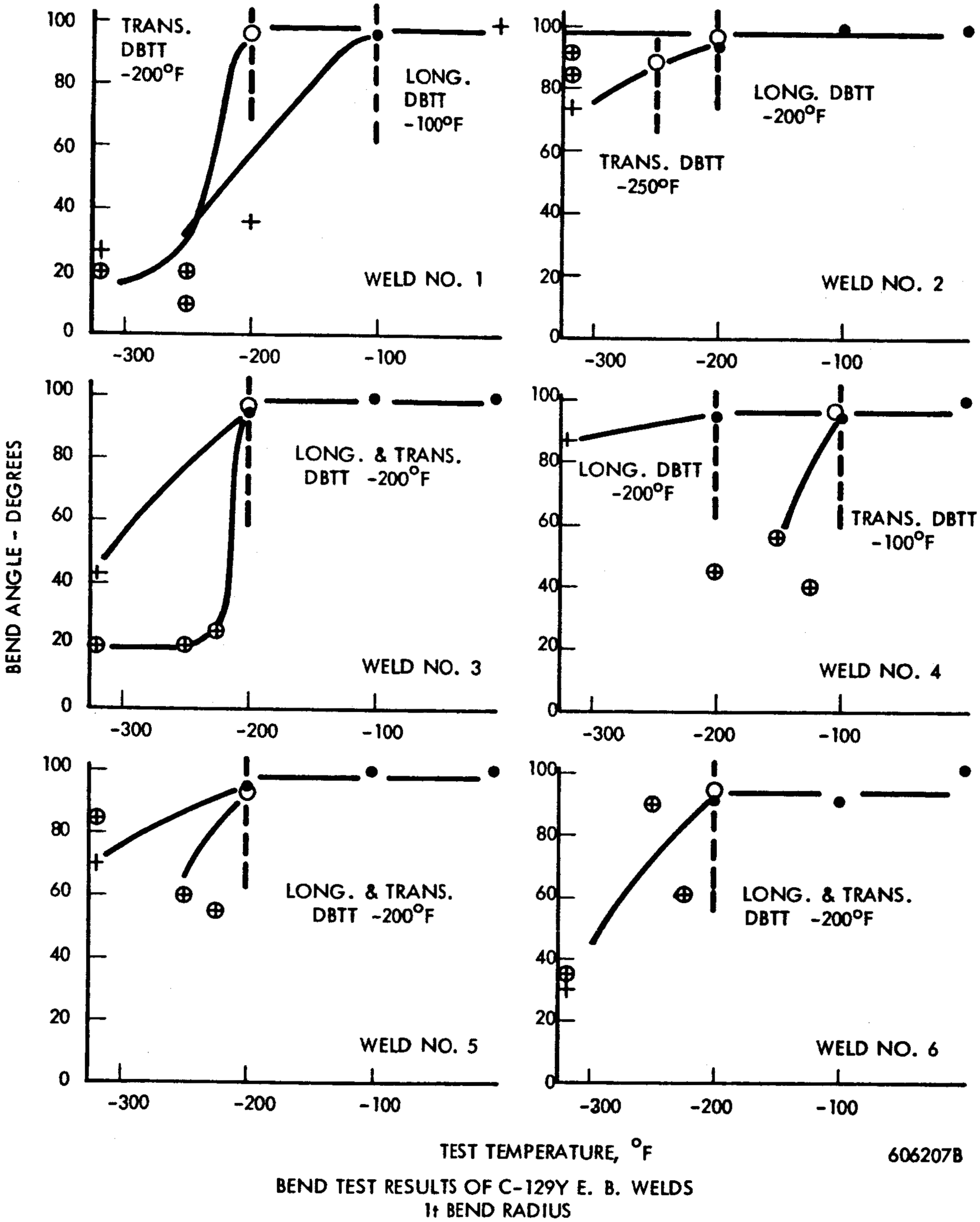
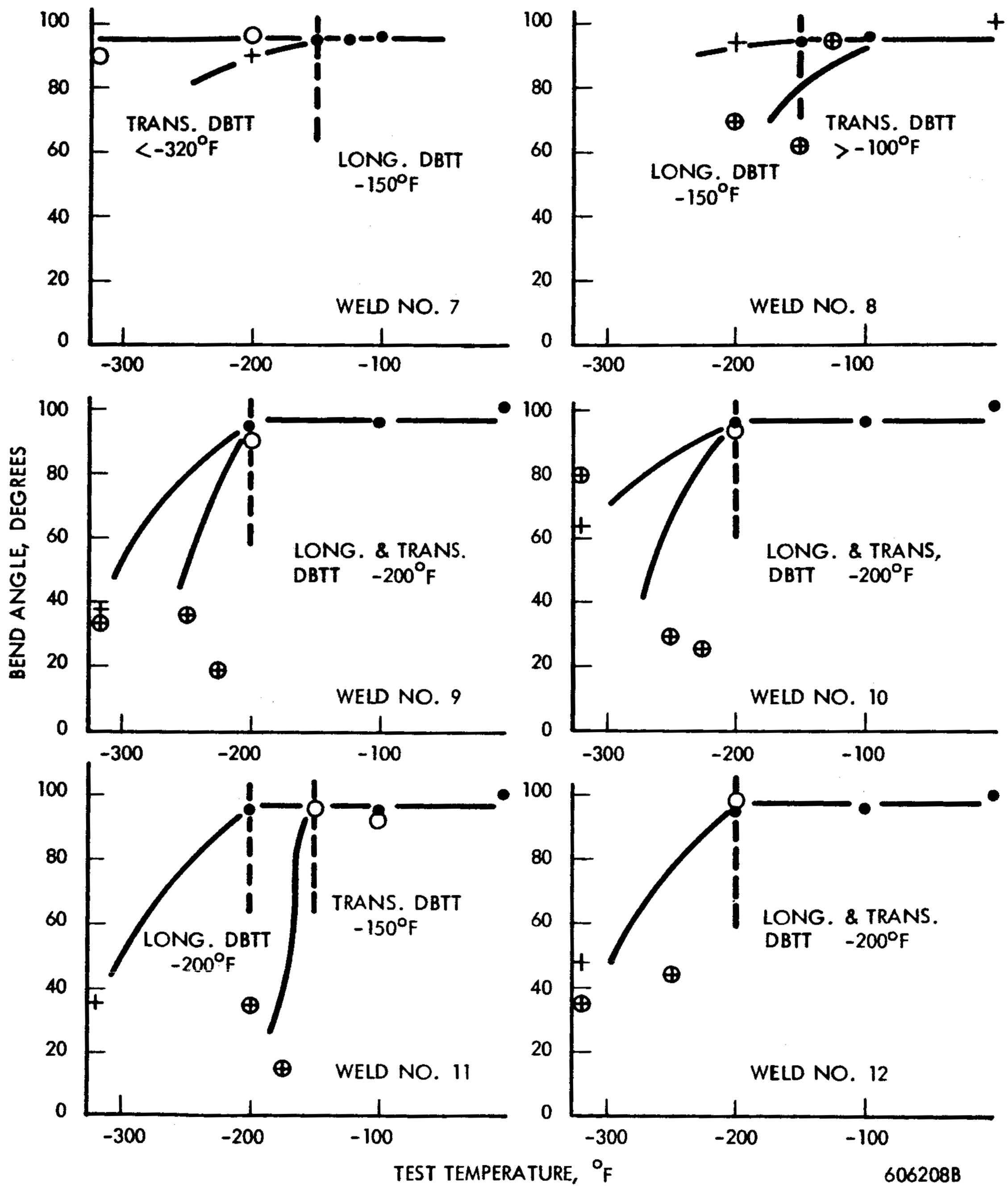


FIGURE 14 - C-129Y EB Weld Bend Test Results



BEND TEST RESULTS OF C-129Y E. B. WELDS
1t BEND RADIUS

FIGURE 15 - C-129Y EB Weld Bend Test Results

TABLE 8 - C-129Y Sheet. EB Butt Weld Record

Weld No.	Speed (ipm)	Deflection[1] (Inches)	Current (ma)	Chill Spacing (Inches)	Power (watts)	Watt-Sec. per inch	Weld Bead Width (Inches)		Vacuum torr	Ave. Weld Bead Width
							Top	Bottom		
1	15	Zero	2.9	.250	435	1740	.040	.032	2×10^{-6}	.036
2	50	L - .050	4.1	.250	615	738	.040	.026	2×10^{-6}	.033
3	100	L - .050	4.6	.250	690	414	.038	.018	2×10^{-6}	.028
4	15	Zero	2.8	.094	420	1680	.031	.025	2×10^{-6}	.028
5	15	L - .050	3.1	.094	465	1860	.039	.027	2×10^{-6}	.033
6	15	T - .050	3.2	.094	480	1920	.061	.054	2×10^{-6}	.058
7	25	L - .050	3.6	.094	540	1290	.039	.030	1.8×10^{-6}	.034
8	50	Zero	3.6	.094	540	648	.031	.019	1.8×10^{-6}	.025
9	50	L - .025	4.0	.094	600	720	.036	.026	1.8×10^{-6}	.031
10	50	L - .050	4.4	.094	660	792	.039	.025	(2)	.032
11	100	L - .050	5.0	.094	750	450	.032	.020	(2)	.026
12	15	L - .050	2.9	.250	435	1740	.043	.036	(2)	.040

1. L. is longitudinal
   T. is transverse

(2) Pressure not recorded.

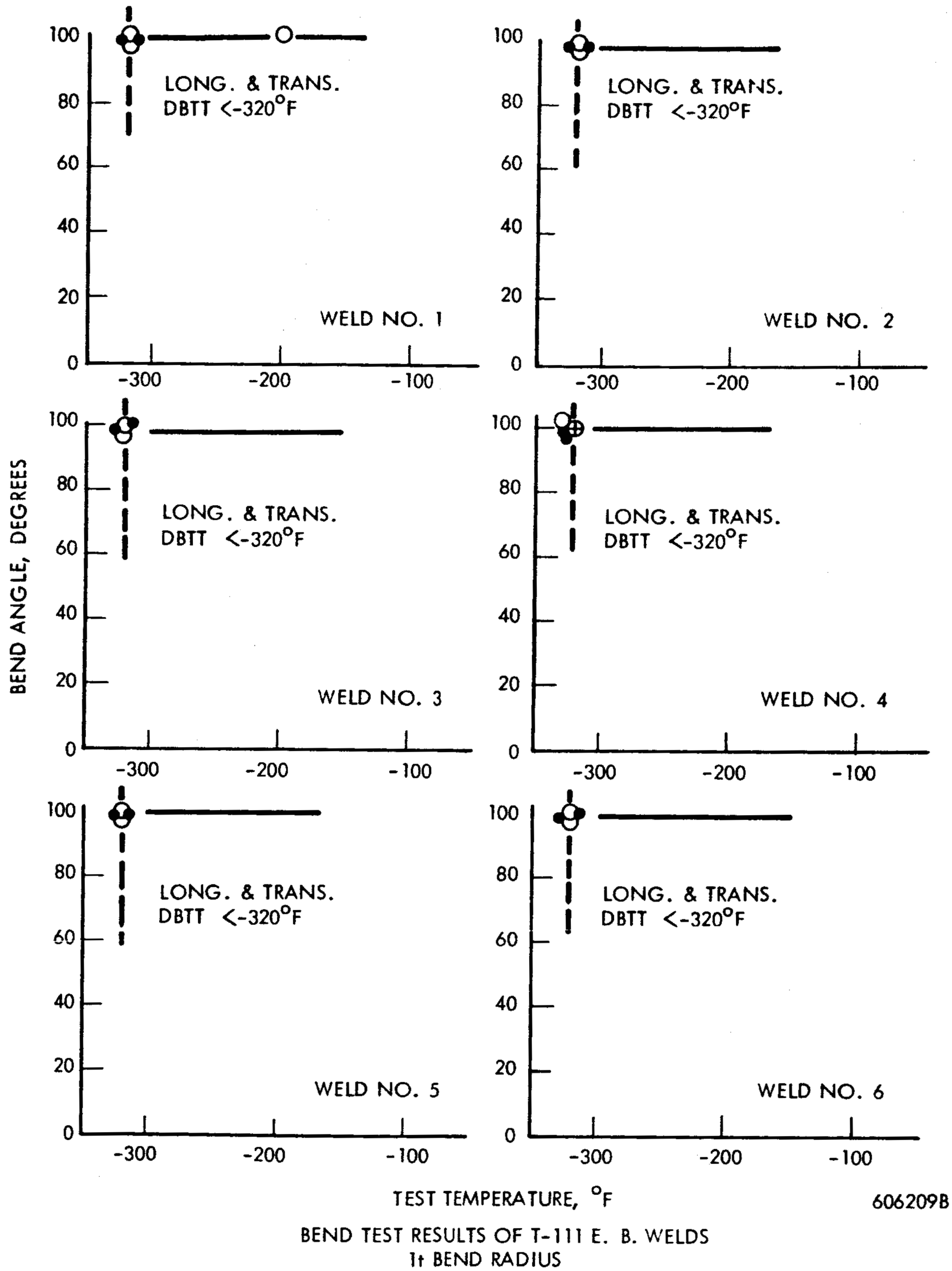


FIGURE 16 - T-111 EB Weld Bend Test Results

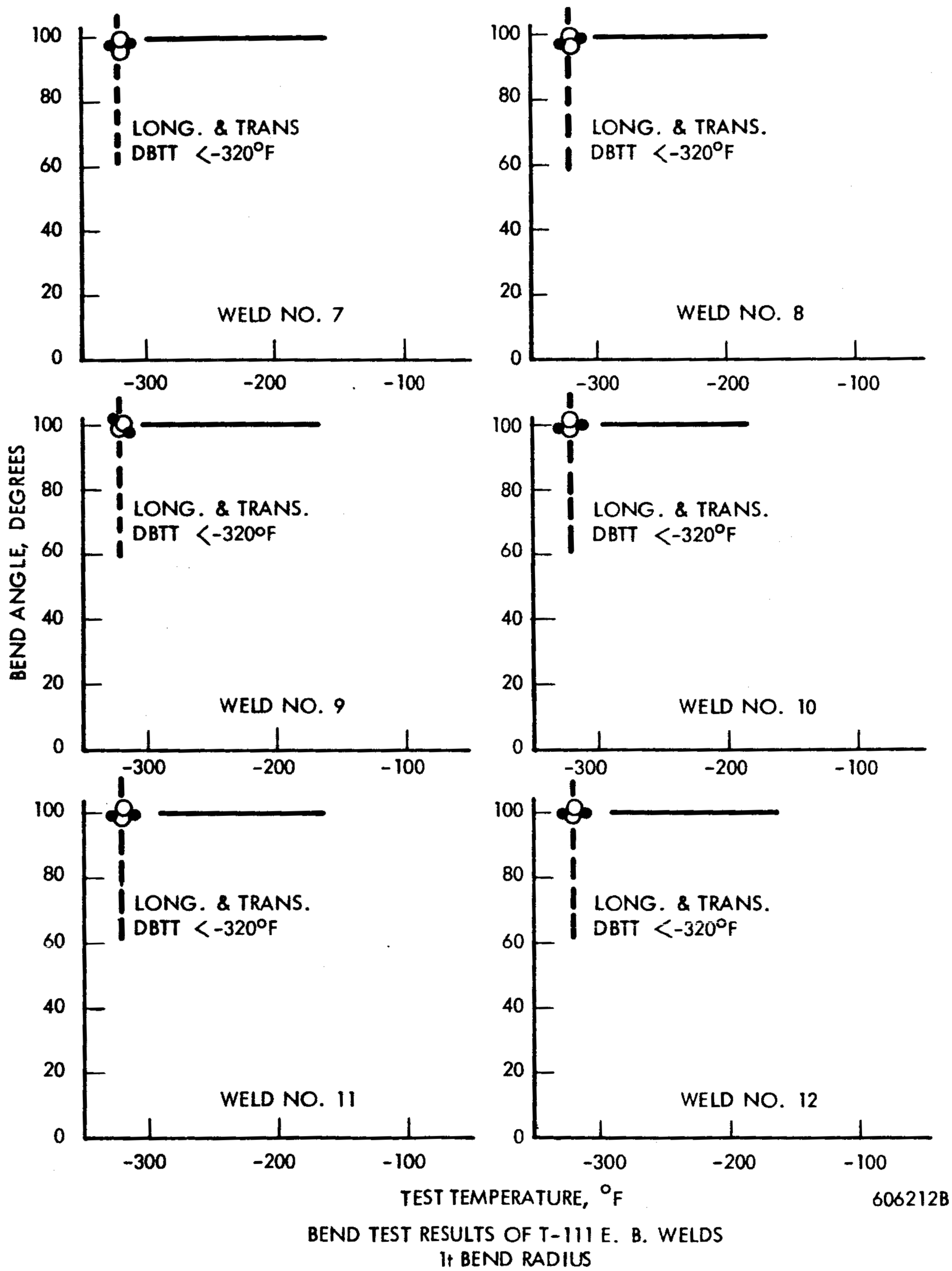


FIGURE 17 - T-111 EB Weld Bend Test Results

TABLE 9 - T-111 Sheet. EB Butt Weld Record

Weld No.	Speed (ipm)	Deflection[1] (Inches)	Current (ma)	Chill Spacing (Inches)	Power (watts)	Watt-Sec. per inch Q	Weld Bead Width (Inches) Top	Weld Bead Width (Inches) Bottom	Vacuum torr	Ave. Weld Bead Width
1	15	Zero	3.6	.094	540	2160	.035	.022	2×10^{-6}	.028
2	15	L - .050	4.2	.094	630	2520	.041	.029	2×10^{-6}	.035
3	15	T - .050	4.2	.094	630	2520	----	----	2×10^{-6}	
4	15	L - .050	3.0	.250	570	2280	.038	.027	2×10^{-6}	.032
5	25	L - .050	4.2	.094	630	1510	.038		(2)	.032
6	50	L - .025	4.8	.094	720	865	.031	.022	2.5×10^{-6}	.026
7	50	L - .050	5.0	.094	750	900	.032	.020	2.5×10^{-6}	.026
8	50	L - .100	5.6	.094	840	1000	.029	.019	2.5×10^{-6}	.025
9	100	L - .050	5.8	.094	870	521	.025	.018	2.5×10^{-6}	.022
10	25	L - .050	4.0	.250	600	1440	.036	.025	2.5×10^{-6}	.030
11	50	L - .050	4.6	.250	690	830	.034	.018	2.5×10^{-6}	.026
12	100	L - .050	5.6	.250	840	504	.026	.018	2.5×10^{-6}	.022

All welds made at 150 KV.
1. L. is longitudinal
   T. is transverse

(2) Pressure not recorded.

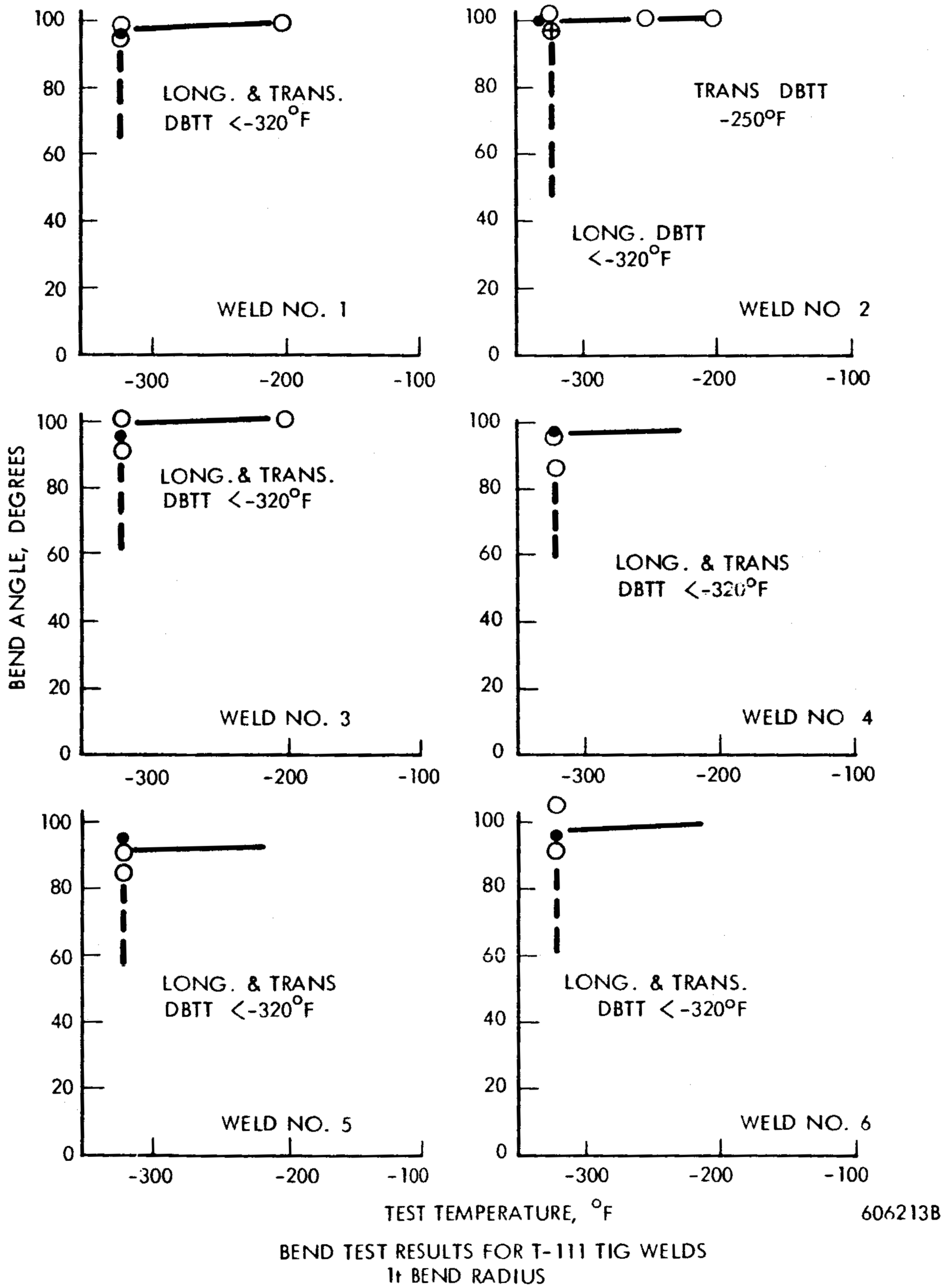


FIGURE 18 - T-111 TIG Weld Bend Test Results

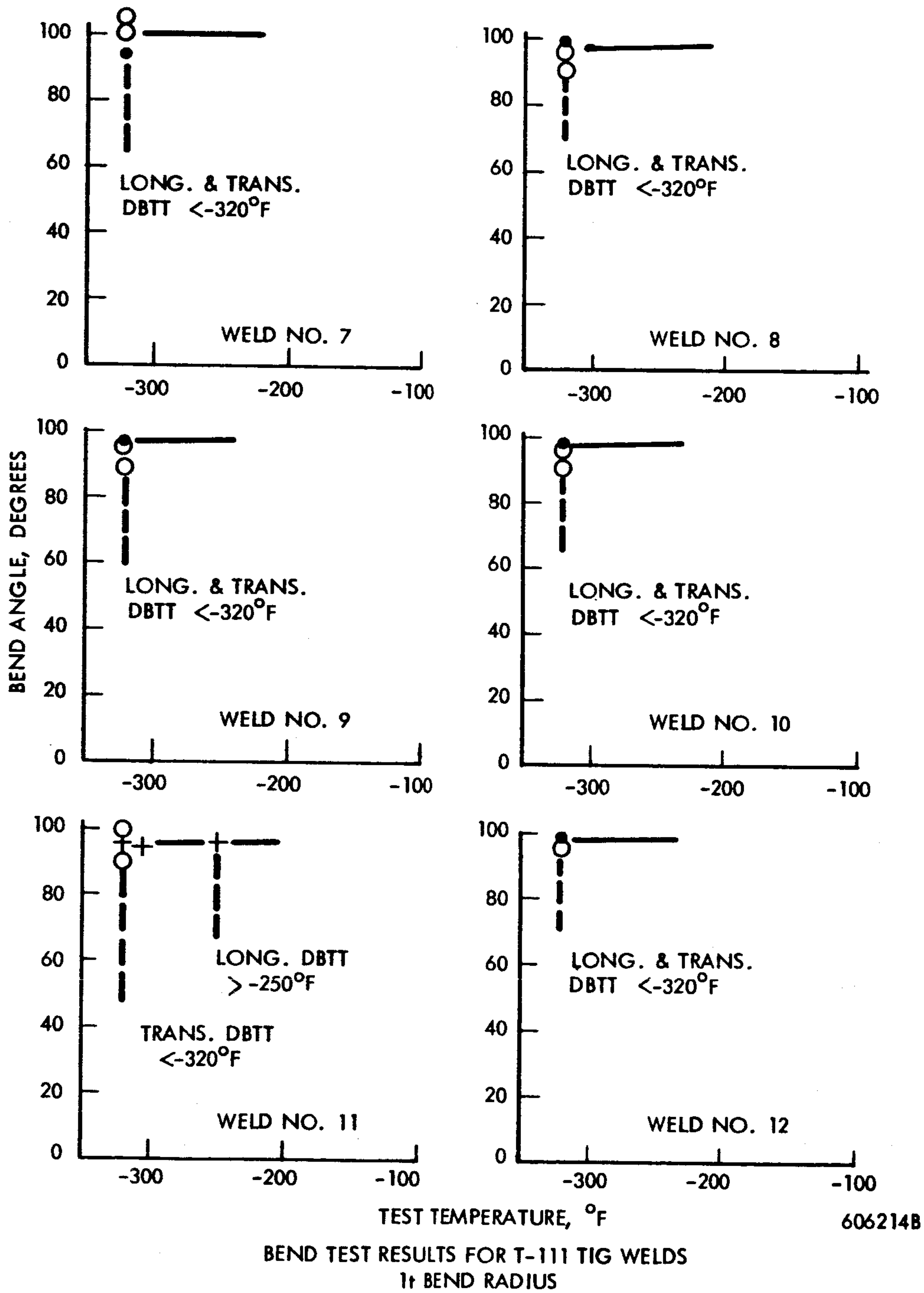


FIGURE 19 - T-111 TIG Weld Bend Test Results

TABLE 10 - T-111 Sheet. TIG Butt Weld Record

Weld No.	Clamp Spacing (Inch)	Speed (ipm)	Current Amperes	Weld Width Top/Bottom (Inch)	Q Joules/Inch	Atmosphere Monitor Readings			Comments	
						O_2(1) ppm	O_2(2) ppm	H_2O(3) ppm	Visual & Dye Penetrant	Radiography
1	3/8	7.5	70	0.123/0.066	9520	1.5	3.0	0.5	Negative	Negative
2	3/8	7.5	90	0.165/0.150	11880	---	3.0	0.6	Negative	Negative
3	3/8	15.0	115	0.195/0.189	8500	---	3.0	0.7	Negative	Negative
4	3/8	15.0	85	0.135/0.084	5780	---	3.6	0.9	Negative	Negative
5	1/4	15.0	90	0.120/0.060	6120	---	4.4	0.9	Negative	Negative
6	1/4	15.0	165	0.210/0.210	11870	---	4.4	0.9	Negative	Negative
7	1/4	30.0	200	0.189/0.180	7600	---	4.4	1.1	Negative	Negative
8	1/4	30.0	125	0.120/0.045	4120	---	4.4	1.1	Negative	Negative
9	3/8	30.0	126	0.150/0.105	4160	3.0	4.0	1.5	Negative	Negative
10	3/8	30.0	185	0.240/0.225	6660	0.5	4.0	1.6	Negative	Negative
11	3/8	60.0	220	0.165/0.138	4180	1.0	3.2	2.5	Negative	Negative
12	3/8	60.0	165	0.117/0.030	2880	1.0	3.2	2.3	Lack of	Penetration

(1) Westinghouse Oxygen Gage
(2) Lockwood & McLorie Oxygen Gage
(3) CEC Moisture Monitor

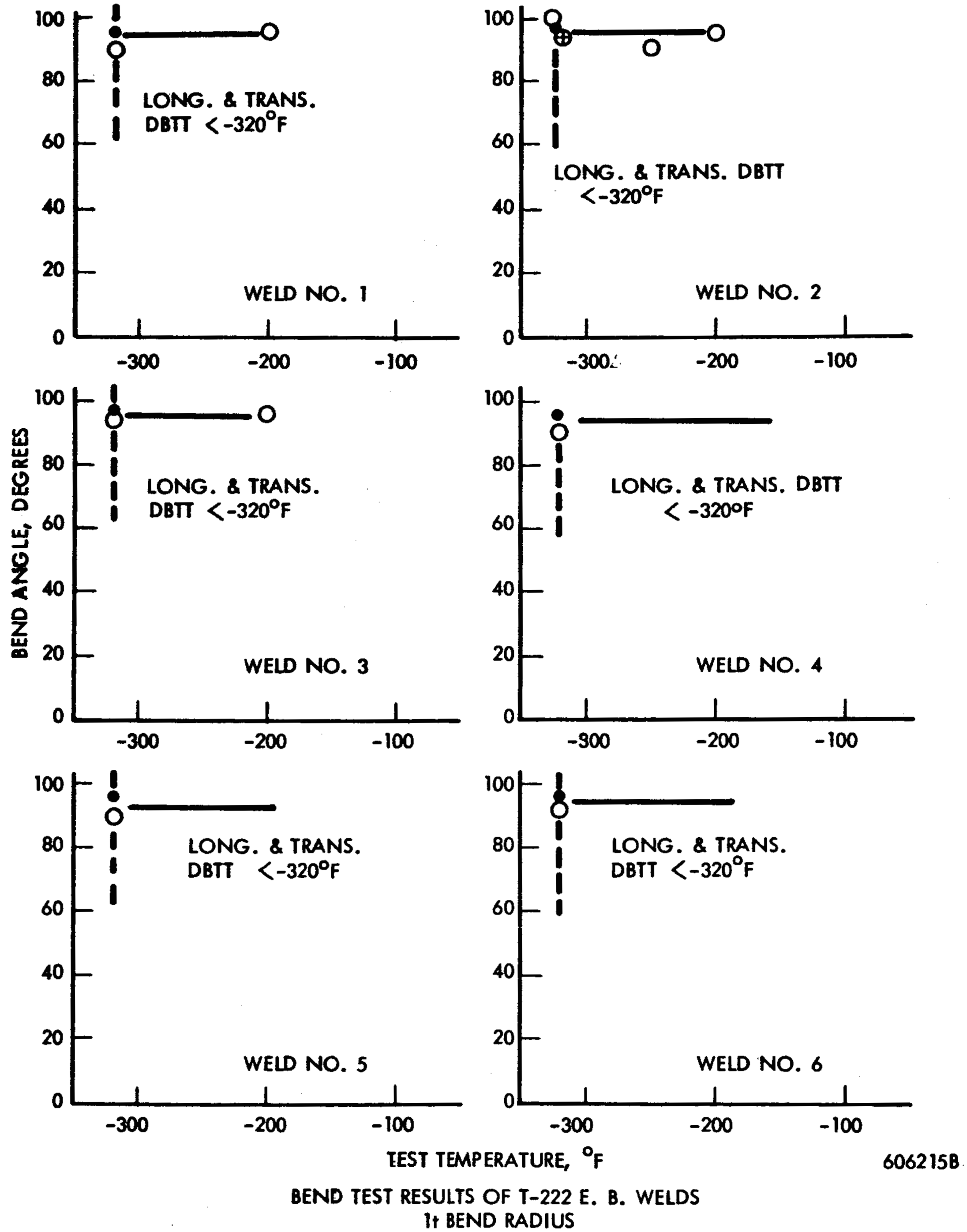
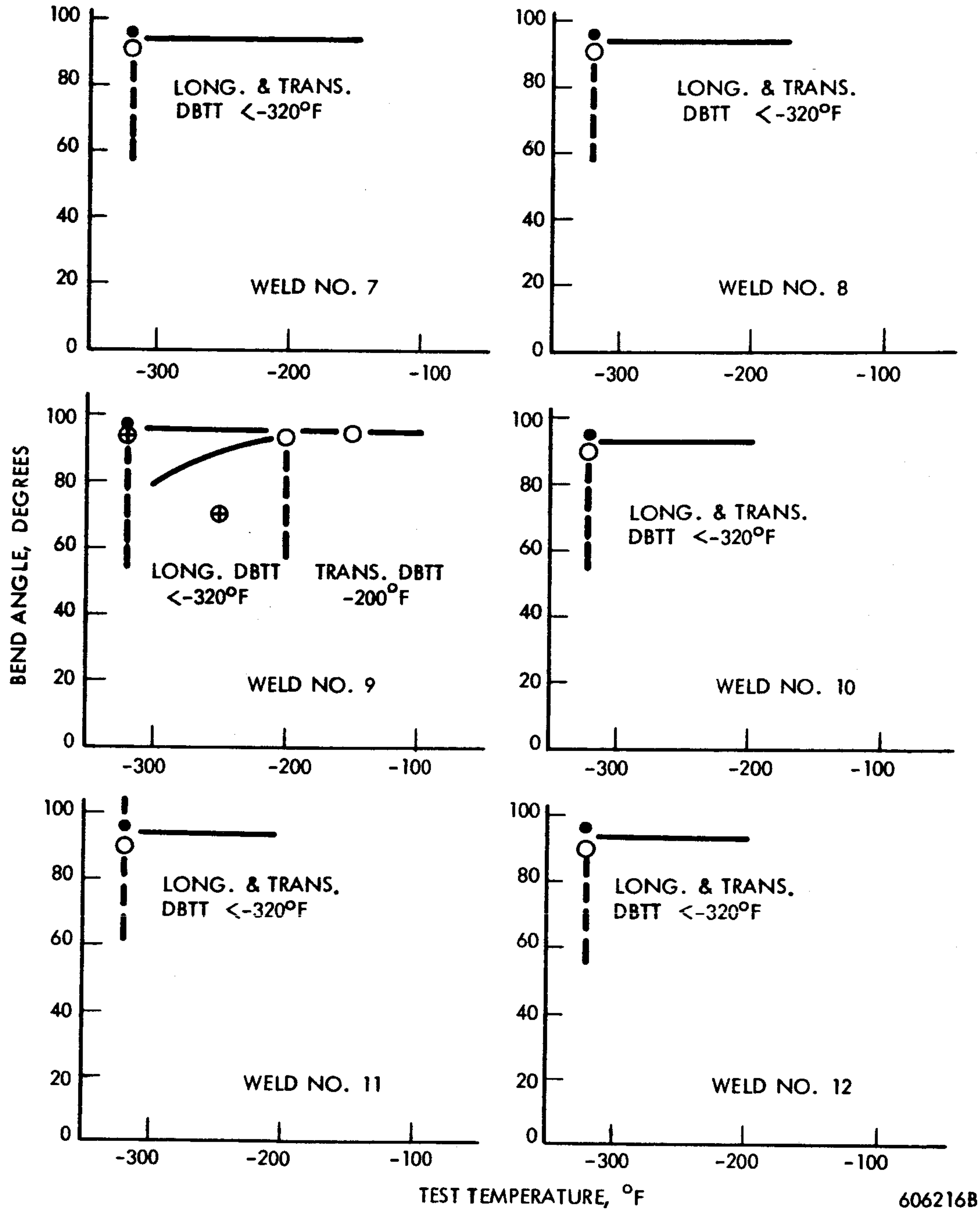


FIGURE 20 - T-222 EB Weld Bend Test Results



BEND TEST RESULTS OF T-222 E. B. WELDS
1t BEND RADIUS

FIGURE 21 - T-222 EB Weld Bend Test Results

TABLE 11 - T-222 Sheet. EB Butt Weld Record

Weld No.	Speed (ipm)	Deflection[1] (Inches)	Current (ma)	Chill Spacing (Inches)	Power (watts)	Watt-Sec. per inch Q	Weld Bead Width (Inches)		Vacuum torr	Ave. Weld Bead Width
							Top	Bottom		
1	15	Zero	3.6	.094	540	2160	.033	.024	2.4×10^{-6}	28
2	15	L - .050	4.2	.094	630	2520	.036	.022	2.4×10^{-6}	29
3	15	T - .050	4.2	.094	630	2520	.065	.060	2.4×10^{-6}	62
4	25	L - .050	4.2	.094	630	1510	.034	.022	2.4×10^{-6}	28
5	15	L - .050	3.8	.250	570	2280	.039	.026	2.4×10^{-6}	32
6	25	L - .050	4.0	.250	600	1440	.036	.023	2.4×10^{-6}	30
7	50	L - .050	4.6	.250	690	830	.031	.018	2.4×10^{-6}	24
8	100	L - .050	5.6	.250	840	505	.027	.019	3.0×10^{-6}	23
9	50	Zero	4.6	.094	690	830	.027	.020	3.0×10^{-6}	24
10	50	L - .025	4.8	.094	720	865	.031	.022	3.0×10^{-6}	26
11	50	L - .050	5.0	.094	750	900	.031	.019	3.0×10^{-6}	25
12	100	L - .050	5.8	.094	870	522	.031	.020	3.0×10^{-6}	26

All welds made at 150 KV.
1. L is longitudinal
   T is transverse

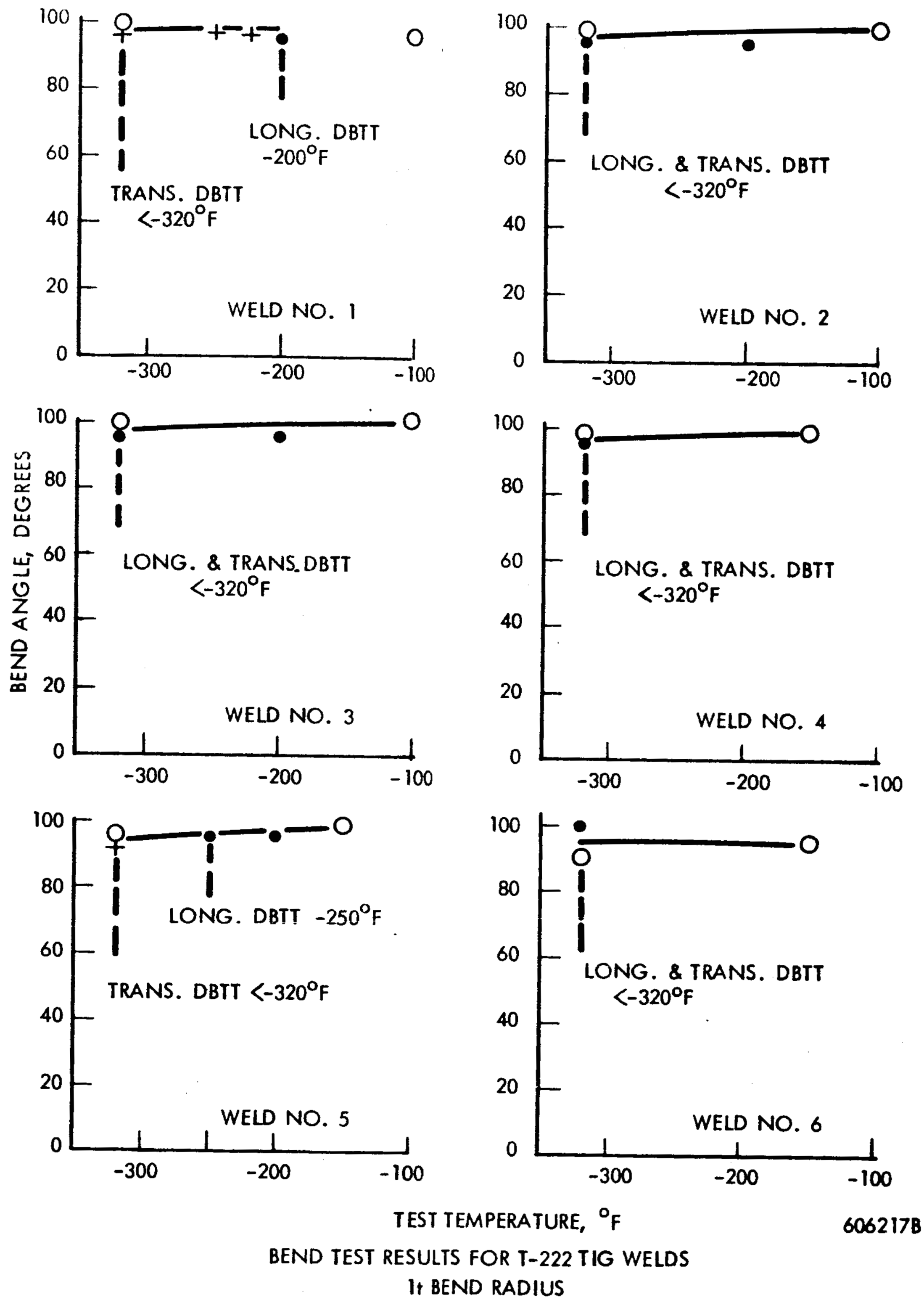


FIGURE 22 - T-222 TIG Weld Bend Test Results

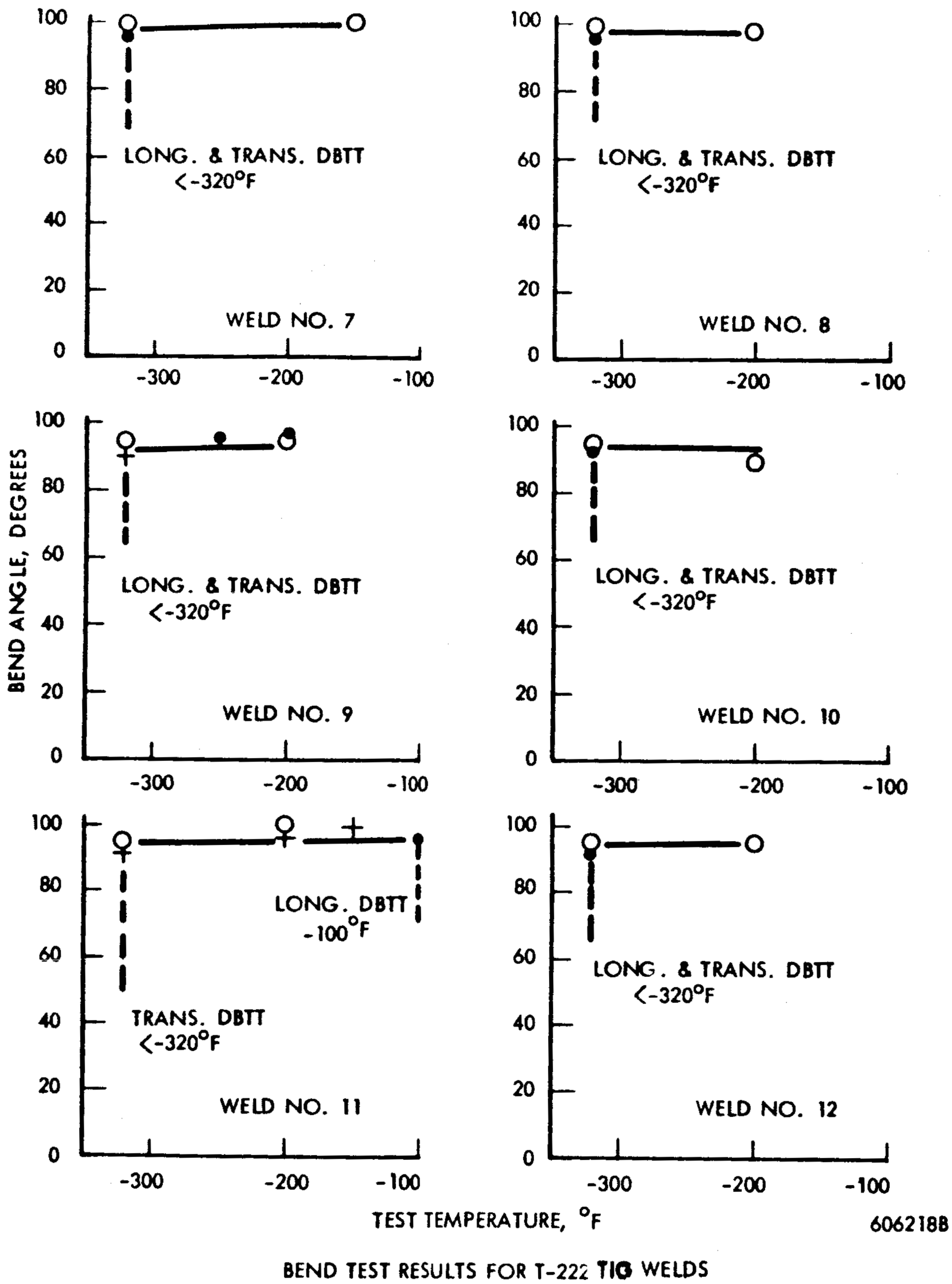


FIGURE 23 - T-222 TIG Weld Bend Test Results

TABLE 12 - T-222 Sheet. TIG Butt Weld Record

Weld No.	Clamp Spacing (Inch)	Speed (ipm)	Current Amperes	Weld Width Top/Bottom (Inch)	Q Joules/Inch	Atmosphere Monitor Readings			Comments	
						O_2(1) ppm	O_2(2) ppm	H_2O(3) ppm	Visual & Dye Penetrant	Radiography
1	3/8	7.5	75	0.141/0.096	10200	---	1.5	0.3	Negative	Porosity
2	3/8	7.5	95	0.182/0.174	13300	---	1.6	0.4	Negative	Negative
3	3/8	15.0	110	0.195/0.171	7480	---	1.6	0.5	Negative	Porosity
4	3/8	15.0	85	0.144/0.105	5780	---	1.6	0.6	Negative	Porosity
5	1/4	15.0	95	0.120/0.072	6460	---	1.8	0.7	Negative	Porosity
6	1/4	15.0	150	0.195/0.190	10800	---	1.9	0.8	Negative	Porosity
7	1/4	30.0	190	0.180/0.159	6830	---	1.8	1.0	Negative	Negative
8	1/4	30.0	133	0.129/0.069	4530	---	1.7	1.2	Negative	Negative
9	3/8	30.0	120	0.135/0.070	4080	---	2.2	2.0	Negative	Negative
10	3/8	30.0	170	0.210/0.189	6120	---	2.4	2.1	Negative	Negative
11	3/8	60.0	220	0.174/0.150	4180	---	2.4	2.3	Negative	Negative
12	3/8	60.0	170	0.120/0.015	3060	---	2.5	2.4	Negative	Negative

(1) Westinghouse Oxygen Gage
(2) Lockwood & McLorie Oxygen Gage
(3) CEC Moisture Monitor

TABLE 13 - Bend Test Results on 3/8 Inch Welded Plate

Alloy	Spec. No.	Type	1st Bend, 16t Rad. Free Bend Angle*	2nd Bend, 8t Bend Rad. Free Bend Angle*	2nd Bend, 8t Bend Rad. Proportional Limit, PSI	3rd Bend, 3t Bend Rad. Free Bend Angle*	3rd Bend, 3t Bend Rad. Proportional Limit, PSI
Ta-10W	3-4	Long.	29° B	57° B	N.D.	141° B	N.D.
Ta-10W	9-10	Trans.	28° B	54° B	N.D.	141° B	N.D.
B-66	1-2	Long.	4° F	---	---	---	---
B-66	9-10	Trans.	4° F	---	---	---	---
C-129Y	1-2	Long.	25° B	49° B	133,740	132° B	128,950
C-129Y	9-10	Trans.	22° B	27° F	147,490	---	---
Cb-752	1-2	Long.	29° F	---	---	---	---
Cb-752	9-10	Trans.	26° B	45° F	90,490	---	---
D-43	1-2	Long.	23° B	39° F	122,730	---	---
D-43	9-10	Trans.	23° B	36° B	106,280	47° F	105,770
FS-85	1-2	Long.	27° B	40° B	160,290	125° F	135,500
FS-85	9-10	Trans.	26° B	40° B	124,030	145° B	119,600
SCb-291	1-2	Long.	23° B	44° B	97,820	160° F	80,200
SCb-291	9-10	Trans.	22° B	37° B	87,810	132° B	94,920

*Letters "B" and "F" in this column designate "Bend" or "Failed" respectively.

ND - Not Determined

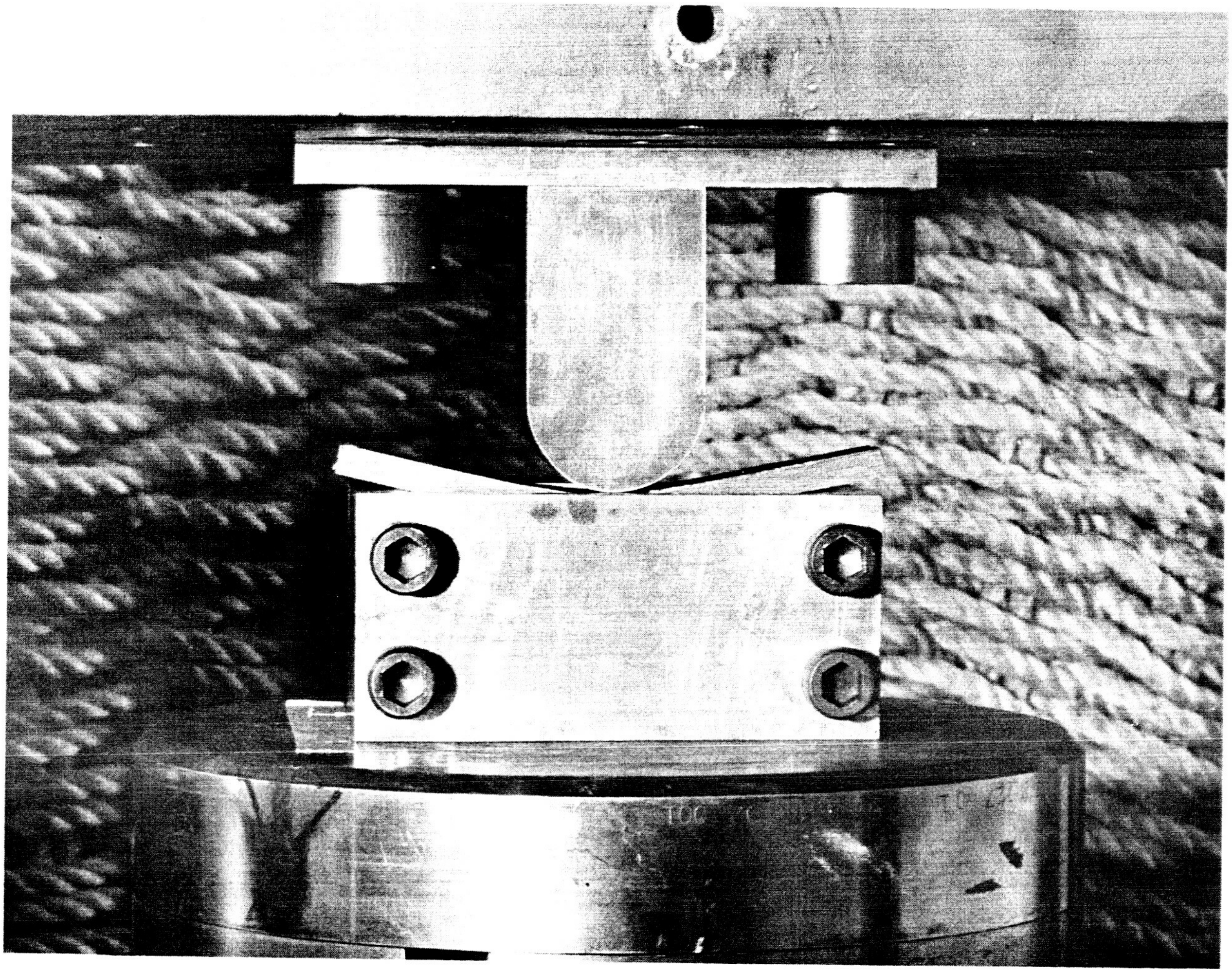
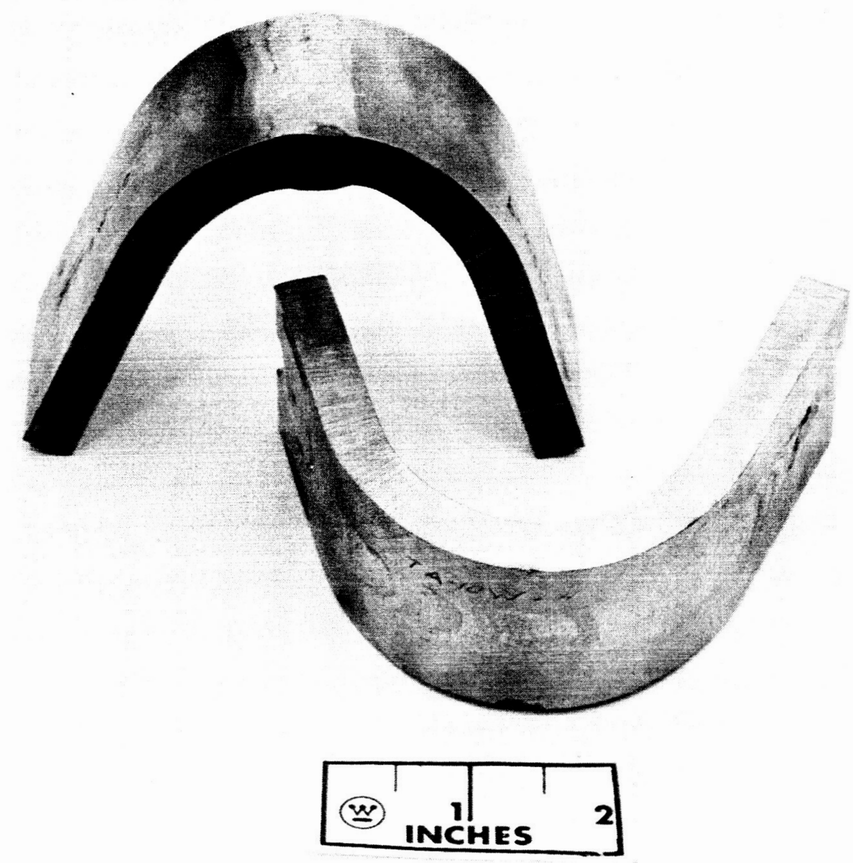


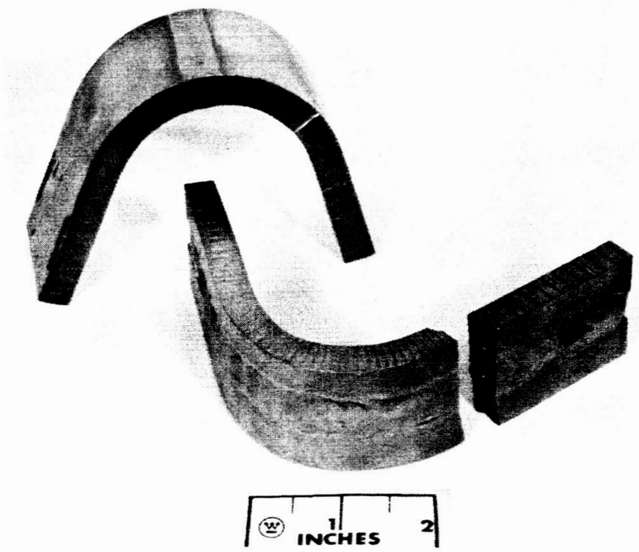
FIGURE 24 - Plate Butt Weld Bend Test Fixture



Ta-10W 435-1

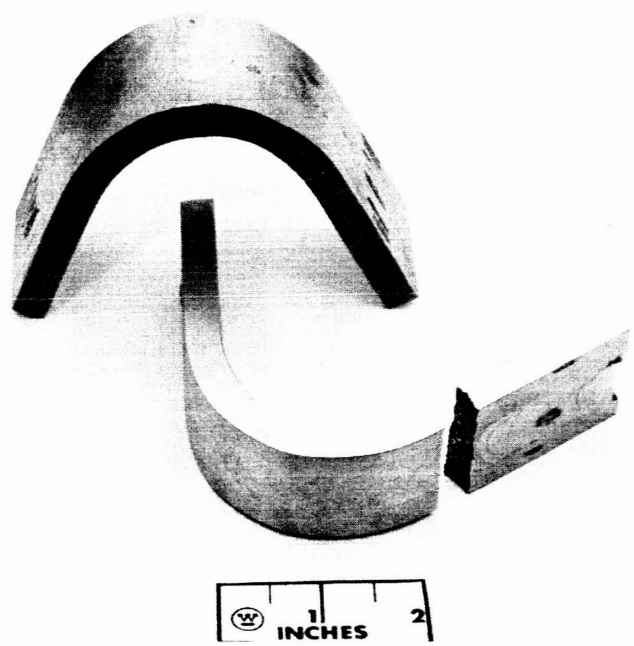
141° Longitudinal Bend
141° Transverse Bend

FIGURE 25 - Ta-10W Plate Weld Bend Specimens



FS-85 427-6

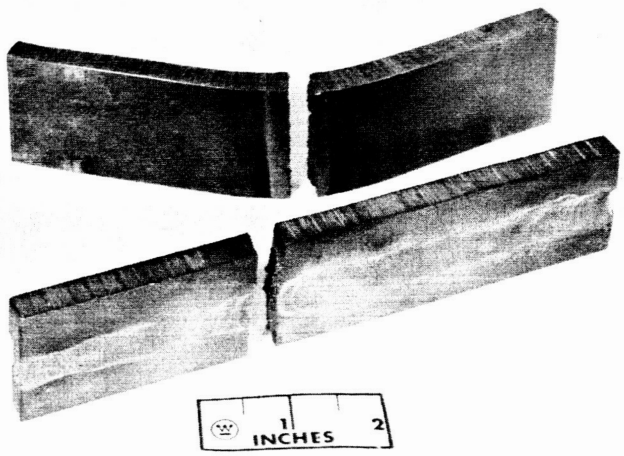
125° Longitudinal Bend
145° Transverse Bend



SCb-291 435

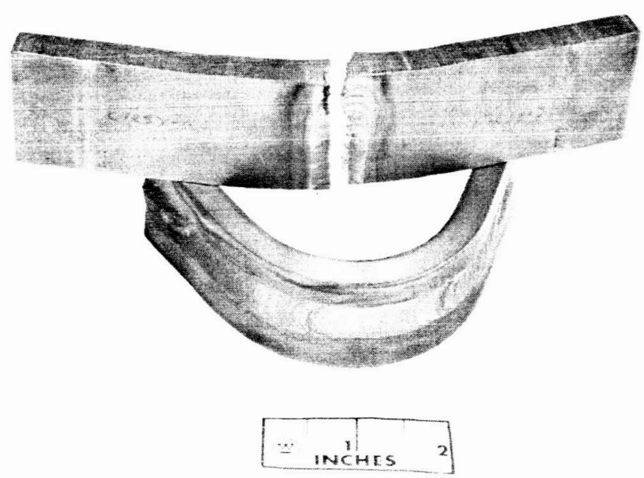
160° Longitudinal Bend
132° Transverse Bend

FIGURE 26 - FS-85 and SCb-291 Plate Weld Bend Specimens



Cb-752 427-2

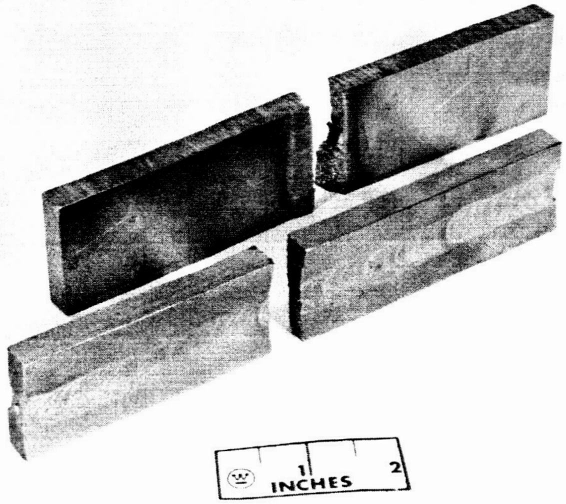
29° Longitudinal Bend
45° Transverse Bend



C-129Y 427-4

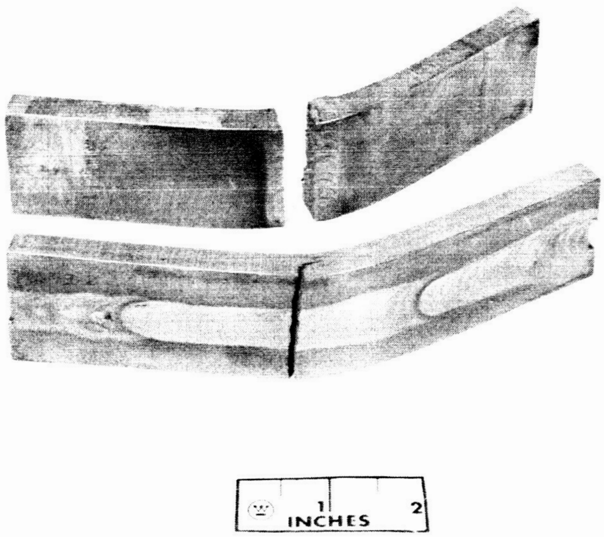
132° Longitudinal Bend
27° Transverse Bend

FIGURE 27 - Cb-752 and C-129Y Plate Weld Bend Specimens



B-66 427-3

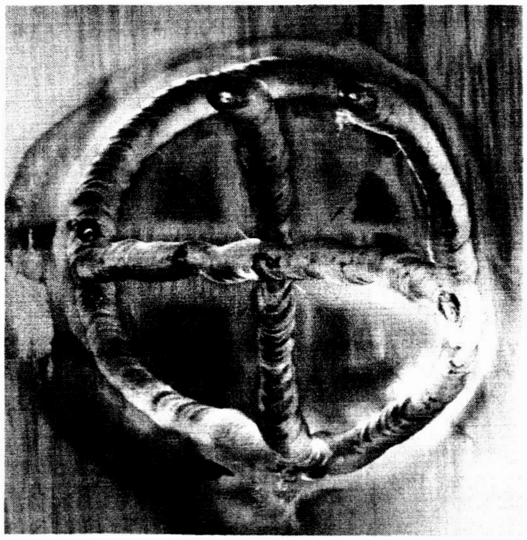
4° Longitudinal Bend
4° Transverse Bend



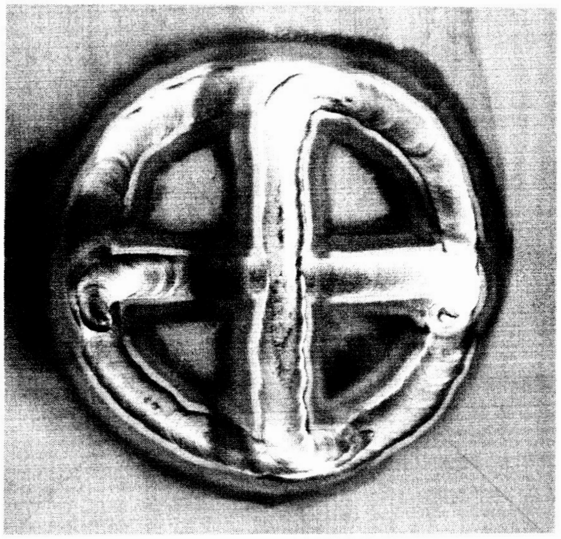
D-43 427-5

39° Longitudinal Bend
47° Transverse Bend

FIGURE 28 - B-66 and D-43 Plate Weld Bend Specimens

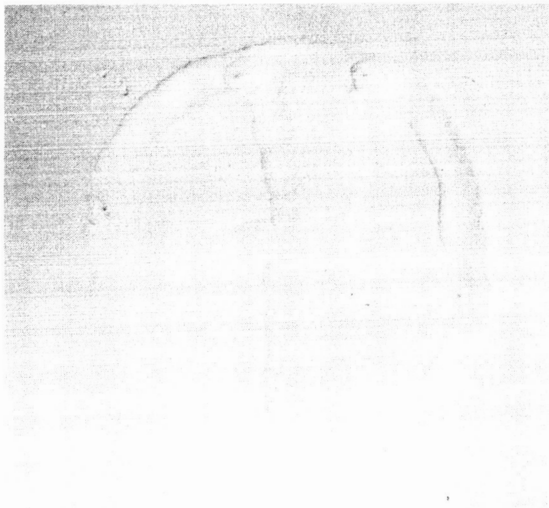


T-111 (X1) 419-3

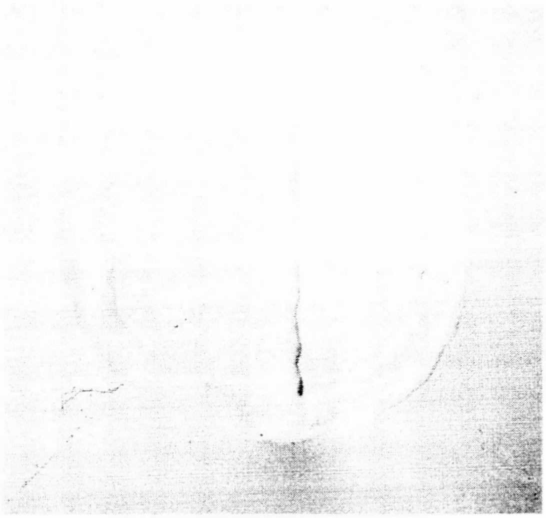


T-222 (X1) 419-1

As-Welded



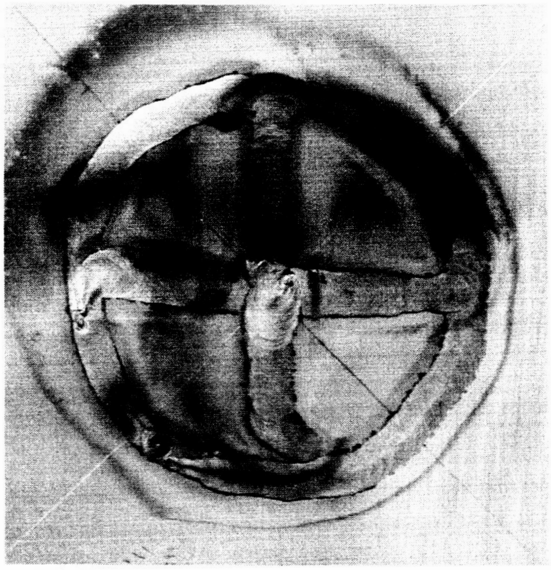
T-111 (X1) 419-5



T-222 (X1) 419-6

Dye Penetrant Inspected

FIGURE 29 - T-111 and T-222 Bead-on-Plate Patch Tests



AS-55 (X1) 419-2

As-Welded

AS-55 (X1) 419-4

Dye Penetrant Inspected

FIGURE 30 - AS-55 Bead-on-Plate Patch Tests

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